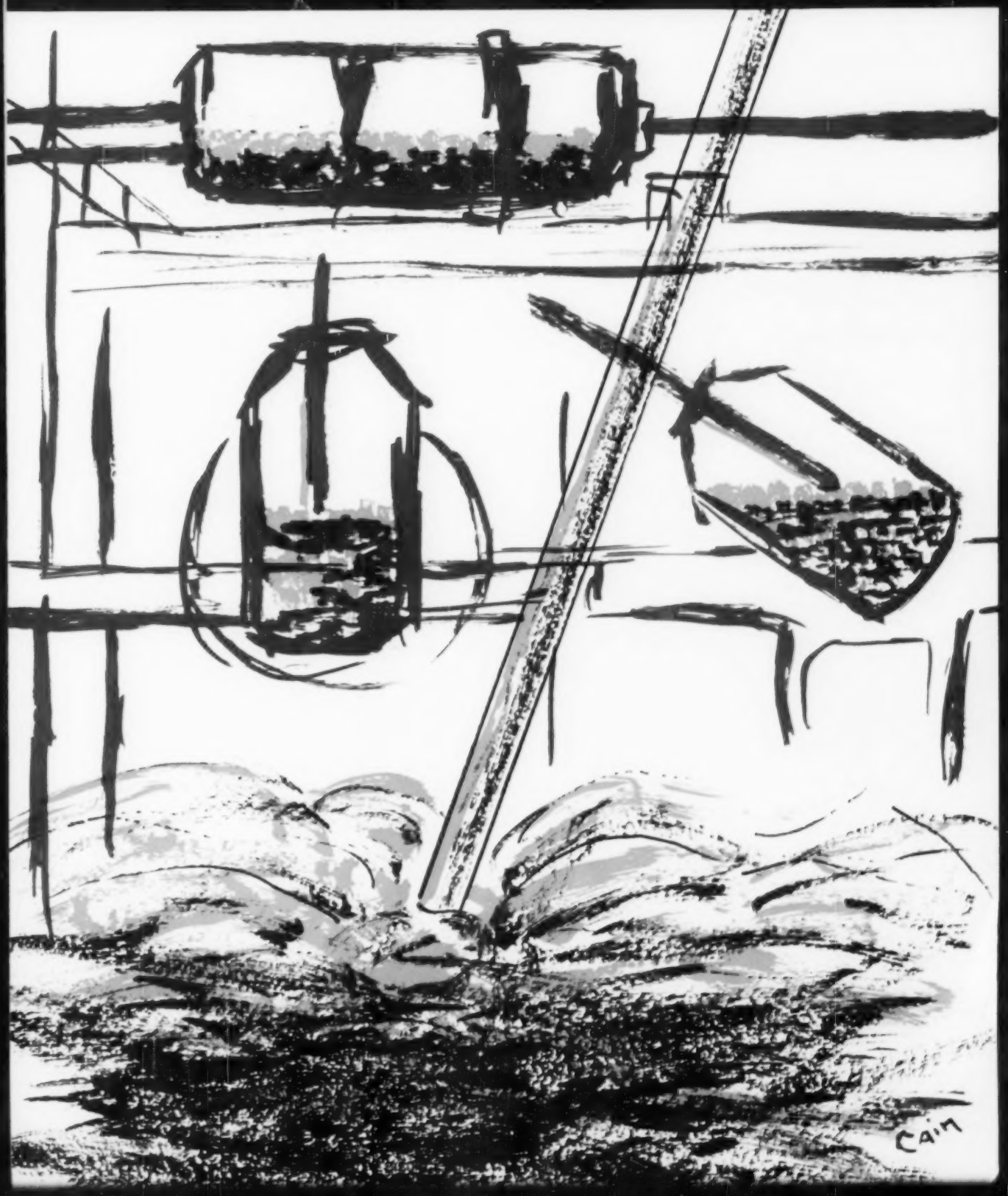
JOURNAL OF

METALS

JULY 1960



This is a throat insert for the nozzle of a solid fuel rocket engine—and it is made possible by a dramatic new isostatic pressing and sintering operation at Sylvania. This operation enables Sylvania to make full use of tungsten, molybdenum and their alloys. It assures rocket and missile manufacturers of a steady and dependable source of supply for the desired refractory metal blanks and ingots.

Forging blanks are no problem for the Sylvania isostatic presses and sintering furnaces; nor are preform blanks for machining or electrodes for arc casting. Sylvania is also equipped to "green machine" the blanks or furnish them to exact finished tolerances.

If refractory metals are your materials, and special shapes, sizes or quantities your problem, you'll find the quality and price Sylvania offers to be of distinct advantage. For details, call your Sylvania representative, or write Chemical & Metallurgical Division, Sylvania Electric Products Inc., Towanda, Pennsylvania.

SYLVANIA

Subsidiary of **GENERAL TELEPHONE & ELECTRONICS**

JOURNAL OF

METALS

Vol. 12, No. 7
July, 1960

COVER: Basic oxygen steelmaking in its three industrially-used processes—Kaldo, LD, and Rotor—served as the inspiration for this cover by David Cain.

contents 497
books 500
education 500
personals 506
reporter 511
letters to editor 514
editorial 515
news of your profession 577
coming events 584
advertisers index 584

Cornerstone Laid for Engineering Center 512
TRANSACTIONS papers accepted 524
LD . . . in the beginning 528
by F. Weston Starratt
Place of Basic Oxygen Steelmaking 529
by A. B. Wilder
Physical Chemistry of Oxygen Steelmaking 531
by D. L. McBride
New Developments in LD Steelmaking 538
by Herbert A. Trenkler
LD Steel from High-Phosphorous Iron 542
by G. Messin, L. Lambert, and G. Helfenstein
Pneumatic Processes for Converting High-Phosphorous Iron 545
by P. Coheur
Notes on Algoma's LD Steel Plant 548
by C. C. Benton and F. C. Muttitt
Soviet LD Steel Installation 552
Dust Removal in Oxygen Steelmaking 554
Metallurgical Characteristics of The Kaldo Process 558
by Bo Kalling, Folke Johanson, and Erik Bengtsson
Discussion 564
by D. R. Berg and T. O. Dormsjo
Bottom Blowing With Oxygen 566
by G. Savard, R. Lee, and M. R. Campbell
NOHC and BFCORMC Meeting Report 570
PHASES AND PROCESSES 574
High Temperature Metals
by C. A. Krier

EDITORIAL STAFF: Editor in Chief, F. Weston Starratt; **Associate Editor,** Harvey Braun, **Production Editor,** Otto Johnson; **News Editor,** R. M. Schelkopf; **Editorial Assistant,** C. M. Cardon.
ADVERTISING SALES MANAGER: Lee Kent, 122 East 42nd St., New York 17, N. Y.
SOUTHEASTERN ADVERTISING REPRESENTATIVE: Fred W. Smith & Associates, 1201 Forest View Lane, Vesthaven, Birmingham, Ala.;
WESTERN ADVERTISING REPRESENTATIVE: Dillenbeck-Galavan Inc., 266 S. Alexandria Ave., Los Angeles 4, Calif.

Address insertion orders and copy to: Advertising Department, JOURNAL OF METALS, 29 West 39th Street, New York 18, N. Y. Send plates to: JOURNAL OF METALS, C/O Lew A. Cummings Co., Inc., 215 Canal St., Manchester, N. H. Published the first day of each month by the American Institute of Mining, Metallurgical and Petroleum Engineers, Inc., 29 West 39th Street, New York 18, N. Y. Telephone: PEnnsylvania 6-9220. Subscription $10 per year for non-AIME members; $6 for AIME members, or $4 additional for members; only in combination with a subscription to "Mining Engineering" or "Journal of Petroleum Technology." Single copies, $1.50. Transactions of The Metallurgical Society of AIME, $5 additional to members, $20 to non-members, and $25 foreign . . . The AIME is not responsible for any statement made or opinions expressed in its publications . . . Copyright 1960 by the American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc. . . . Registered address, AIME New York . . . Indexed in Engineering Index, Industrial Arts Index, and Chemical Abstracts . . . Second class postage paid at New York, N. Y., and at Manchester, N. H. Numbers of copies in this issue, 11,650.

personnel

- These items are listings of the Engineering Societies Personnel Service, Inc. This Service, which cooperates with the societies of Civil, Electrical, Chemical Mechanical, Mining, Metallurgical, and Petroleum Engineers, is available to all engineers, members and non-members, and is operated on a nonprofit basis. If you are interested in any of these listings, and are not registered, you may apply by letter or resume and mail to the office nearest your place of residence, with the understanding that should you secure a position as a result of these listings you will pay the regular employment fee of 60% of the first month's salary if a non-member, 50% if a member. Also, that you will agree to sign our placement fee arrangement which will be mailed to you immediately after receiving your application. In sending applications be sure to list the key and job number. The New York office of Engineering Societies Personnel Service, Inc., is open for interviews until 7:00 p.m. Thursday evenings.
- When making application for a position, include eight cents in stamps for forwarding application to the employer and for returning, when possible.

—MEN AVAILABLE—

All those listed under "Men Available" have membership in the AIME.

Physical Metallurgist; B.S. Met. Eng., age 42. Eighteen months as commodity industry analyst, 18 months application engineer for rock crushers, four years mineral dressing (metallurgical and non-metallurgical), one year sintering and smelting, one year physical metallurgy (aluminum and steel). Prefer metropolitan area. M-235.

Metallurgist-Supervisor; B.S., M.S., age 36, plus graduate study and teaching. Ten years industrial research and development experience, largely at the supervisory level. Broad background in physical metallurgy, processes, properties, testing, applications. Desire significant responsibility and opportunity developing and directing technical program at $13,500 level. M-236.

Plant Manager; B.S. Met. Eng. Fourteen years of operating metallurgy in iron and steel casting and fabrication. Managed melting, heat treat, and metallurgy departments; supervised 50 people. Experienced in plant and equipment expansions, customer service, and planning. Prefer East or Midwest. M-237.

Metallurgist; MetE, age 27. Four years research and development with mining company in new smelting practices, modernization of operation, trouble shooting, and new uses for lead and lead alloys. Military service completed. Se-1380.

Physical Metallurgist; Met, age 32. Experience in nonferrous semi-finished products' quality and production control. Also alloy development on manganese-base alloys. $6500. Prefer West. Se-1138.

Chief Metallurgist; MetE, age 34. Ten years diversified experience in ferrous and nonferrous foundry . . . cold and hot forging . . . production . . . and research and development of titanium . . . stainless . . . superalloys . . . creep . . . and fatigue. $12,000. Prefer West. Se-1025.

Address replies for positions to the nearest local office of the Engineering Societies Personnel Service, Inc., *not* to the JOURNAL OF METALS. Offices are located at 29 E. Madison St., Chicago 1, Ill. . . . 57 Post St., San Francisco, Calif. . . . and 8 W. 40th St., New York 18, N. Y.

—POSITIONS OPEN—

Research Director in the field of die cast technique and metallurgy. For large manufacturer of die cast parts. Must have education in the scientific and/or manufacturing technique. Must have the inquiring-mind approach to die casting. Salary, open. Location: upstate N. Y. W9087.

Technical Personnel. a) Chief Metallurgist to manage a small research department. Should have knowledge of foundry practices, all forms of heat treating, and should know plating. Product is a component for engines. Salary, $12,000-$14,000, plus bonus. b) Chemist with knowledge of chemical analysis for foundry operations, plating, cleaning materials, and analysis of metals, such as steel and cast iron. Will report to chief metallurgist. Salary, approximately $8400, plus bonus. Location: western Mich. W9070.

Metallurgist who is primarily experienced in ore dressing of various kinds. Salary, open. Location: South. W9068.

Metallurgists. a) Senior development and research metallurgist with five years experience in metallography and alloy steel or iron laboratory, plus experience in direction of laboratories. Will work on development and research of iron and steel rolls . . . supervise research laboratories . . . do metallographic examination . . . and write reports on returned rolls. Salary, $9600. Location: Midwest. b) Research metallurgist with M.S. in Met. Eng. to conduct experimental work under supervision of chief metallurgist in development alloys. Salary dependent on training and experience. Location: western Pa. W9015.

Engineers. a) District sales manager with degree. Must have three years selling some steel component and some alloying ingredient. Duties will entail selling ferrochrome to steel and foundry industry. b) Metallurgist; graduate with three or more years experience and contact with technical departments of steel companies. Must know steelmaking procedures. Will contact technical personnel of the steel industry on problems and questions concerning the use of ferrochrome in steelmaking. Salaries to $12,000. Employer will pay fee. Traveling and car required. Location: Pittsburgh-Youngstown area. C8103.

Consultant; metallurgist with wide metallurgical experience in copper smelting and refining, and familiarity with operation and engineering in copper-producing areas throughout the world. Will provide technical direction for metallurgical plant and design construction, also technical assistance to operate smelters and refineries, plus handling developmental work for new methods. Must be top-notch with sound economic sense and be capable of contact work under a variety of circumstances, including top management. Salary commensurate with experience. Headquarters: Mountain States. Sj-5265-R.

Research Metallurgist; Met, with ore dressing experience. For laboratory research in large copper mine in the southwest. Apply by letter. Salary, open. Sj-5241.

Research Metallurgist, preferably with Ph.D. or equivalent. For research and development in physical metallurgy of aluminum alloys. Salary commensurate with experience, plus liberal employee benefits. Location: Pacific Northwest. Sj-5240.

Assistant Supervisor for material control laboratory. Young graduate in mechanical, metallurgical, or chemical engineering with background in metallurgy. Laboratory does mechanical testing and chemical analysis of raw materials. Salary, about $7020. Location, Conn. W9044.

Metallurgists: BS or MS degree in metallurgy, with two to five years experience in alloy development, phase diagrams, physical property determinations of nonferrous metals. Will be responsible for carrying out research programs on beryllium containing alloys. Salary open. Location Reading, Pennsylvania.

Box 8-JM.

NEW BULLETIN

A new bi-weekly bulletin of "Engineers Available" is now being published by the Engineering Societies Personnel Service, Inc. Distributed free of charge, the bulletin contains synopses of the experience of engineers who have registered with the Service and are seeking a new position.

Any employer interested in receiving the bulletin should so advise E.S.P.S. at 8 W. 40th St., New York 18, N.Y., and your name will be placed on the mailing list. Any engineer who is registered with the Service or wishes to register is entitled to a 35-word notice in the bulletin. Write to the New York office for forms. Your qualifications will be brought to the attention of employers on our mailing list without revealing your identity.

It is planned to extend the publication to the midwestern and western offices in the near future.

TECHNICAL MEN NEEDED

PERMANENT POSITIONS
OPPORTUNITY FOR ADVANCEMENT

ENGINEERING DEPARTMENT:

Physical Metallurgist—B.S. Degree required.
Experience—Mine and Mill operations for one year or more.
Duties—Research in application of wear resistant alloys.

Industrial Engineers—B.S. Degree required.
Experience—1 year required.
Duties—Work measurement and cost control.

Engineers Assistants—B.S. Degree required (mining preferred)
Experience—Not required.
Duties—Underground surveying for the mine department, drafting, calculating and design.

Assistant Geologist—B.A. in Geology—minimum requirement.
Experience—Not required but desirable.
Duties—Underground and surface geology mapping, logging drill cores compilation and miscellaneous.

Design Engineers—B.S. in Civil Engineering.
Experience—6 months—1 year.
Duties—Design of Tailings Disposal Facilities.

An excellent opportunity to become a part of one of America's most vital industries. Unlimited future for qualified men. Excellent housing facilities for families. Board and room for single men.

Further information may be acquired by writing to:

CLIMAX MOLYBDENUM COMPANY
CLIMAX, COLORADO

The Story Behind a $35,000,000 STEEL-MAKING FACILITY...

Photo, courtesy of Acme Steel Company, Riverdale, Illinois, high-lighting new steel-making facility.

Major Engineering by MOHR

How the MOHR organization can supply the engineering know-how on steel-making expansion programs of any magnitude is demonstrated by Acme's new facility at Riverdale.

Applying their long experience and guidance in translating the customer's requirements, MOHR, working closely with Acme engineers, provided the major engineering for this $35,000,000 project. This included basic layout, foundations, structural and mechanical design, together with required specifications.

The new facility provides cupolas to convert scrap and pig iron into molten iron; oxygen furnaces to convert iron into steel; ingot pouring and stripping areas; soaking pits; and rolling mills to produce slabs and billets.

Whether your plans call for the development of a new project such as this, or the expansion of existing facilities, MOHR engineers are ready to counsel with you and carry out their recommendations with complete engineering, fabricating and contracting services.

Your inquiry will receive prompt attention.

JOHN MOHR & SONS

Engineers • Fabricators • Contractors • Since 1857

3200 East 96th Street • Chicago 17, Illinois

new books

Books that are marked (•) may be ordered through AIME. Address Irene K. Sharp, AIME Book Dept., 29 W. 39 St., New York 18, N. Y. A discount is given whenever it is possible.

Symposium on Electron Metallography STP 262, 134 pp., $4.25, 1960—This volume consists of the 11 papers on electron metallography presented during the American Society for Testing Materials' 1959 Annual Meeting. The contents include: *Electron Microstructure of Precipitation-Hardenable Austenitic and Nickel-Base Alloys*—Sixth Progress Report of Subcommittee X1 on Electron Microstructure of Metals . . . *Morphology of Phases in High-Temperature Alloys as Revealed by the Electron Microscope*, by J. R. Mihalisin . . . *Simplified Electron Metallography of Steels*, by G. E. Pellissier . . . *Techniques for Studying Structure and Growth of Tin Oxide by Electron Microscopy*, by P. S. Trozzo . . . *Electron Metallography of Neutron-Irradiated Steels*, by R. F. McCartney and P. S. Trozzo . . . *Electron Microscopy of Tin Plate*, by P. A. Stoll . . . *Instrument Modifications for Routine Electron Diffraction*, by G. R. Grieger . . . *Structure Analysis with Routine Electron Diffraction*, by G. R. Grieger . . . *A Simple Application of the Carbon Replica Technique*, by L. Pellier . . . *Observations of Dislocations in Thin Foils of Stainless Steel with the Electron Microscope*, by R. M. Fisher and A. Szirmae . . . and *Microstructure of a Cast Age-Hardenable Nickel-Chromium Alloy*, by R. F. Decker and C. G. Bieber.

Forschungsberichte des Wirtschafts und Verkehrsministeriums Nordhein-Westfalen, *Westdeutscher Verlag, Köln.*

No. 519—**Die spektrographische Bestimmung der Spurenelemente in Stahl ohne vorherige Abtrennung,** by F. Wever, W. Koch, and S. Eckhard, 36 pp., approx $3.15, 1958—This is a description of the moving electrode method used in conjunction with the spectrograph to detect impurities in iron. Although the process does not employ the usual chemical separation, it does detect traces of elements as low as 0.0001 pct Al or 0.0003 pct Mn.

No. 456—**Zeitstandversuche an austenitischen Stählen und Legierunger,** by K. Bungardt, 84 pp., approx $5, 1958—This report gives the results of tests on the creep properties of chrome, molybdenum, nickel, titanium, columbium, and tungsten alloys performed at the Max Planck Institut.

No. 492—**Zur Theorie der irreversibilen Prezesse in α-Eisen,** by J. Meixner and B. Manz, 22 pp., approx $1.50, 1958—This paper discusses the theory of damping, relaxation, diffusion, and heat transmission in alpha iron, based on the thermodynamics of the irreversible processes. This approach serves as a tool to treat these phenomena in a general and systematic way, and to extend the analogy to all dynamic-elastic processes.

Forschungsberichte des Landes Nordhein-Westfalen, *Westdeutscher Verlag, Köln.*

No. 798—**Einfluss der Schutzgasatmosphäre auf die Eigenschaften von Sinterstahl,** by K. Wassmann, 94 pp., approx $6.75, 1959—This is a comparison of several gases, based on their effects on the mechanical properties of products made of pure iron, iron-graphite, and iron-copper powder mixtures.

No. 841—**Untersuchungen zur Kinetik des Martensitzerfalls,** by H. Blank, 33 pp., approx $2.50, 1960—This paper describes investigations on precipitation velocity, based on the temperature-precipitation curves.

PROJECT SUPERVISOR: Ph.D., or equivalent degree, in metallurgy possessing at least 3 years experience in alloy design and development on a research level. To act as project supervisor in the investigation of new or improved beryllium containing alloys in a broad basic research program. Salary open. Location Reading, Pennsylvania.

Box 9-JM.

Research Metallurgist

Opportunity with large Western Pennsylvania research and development organization for PhD with experience. Physical metallurgy research on the effect of chemical composition, hardenability, heat-treating variables and microstructure, including grain boundry constituents, on desired properties of alloy steels. Reply giving complete information and salary requirements to Box No. **11-JM.**

Physical Metallurgist

Opportunity in large Western Pennsylvania research and development organization for recent BS or MS graduate having sound educational background in physical metallurgy. Applicants with knowledge of X-ray diffraction and metallography preferred. Experience desirable but not essential. Reply giving complete information and salary requirements to Box No. **12-JM.**

education

MATERIALS RESEARCH

The Massachusetts Institute of Technology has been awarded $599,200 by the National Science Foundation for materials research.

The research will concentrate on two fields: low temperature and related studies, and research in neutron physics. Together, the work is expected to produce more complete understanding of some of the lesser-known materials.

Changes that take place at varying low temperatures in ferromagnetic, ferroelectric, and organic materials will make up that phase of research. To detect these changes, MIT scientists will measure the associated heat properties of materials, and study their structures by bombardment with X-rays and neutrons. Nuclear magnetic resonance and other special techniques also will be used.

In the neutron physics studies, a polarized beam spectrometer and other equipment will help determine crystal structure and magnetic properties.

A special group called the Laboratory of Chemical and Solid State Physics has been created for this materials research. Headed by John C. Slater, the group is composed of more than 100 staff members, predoctoral and post-doctoral students, and research workers from the departments of physics, chemistry, metallurgy, and mechanical engineering.

CASTINGS RESEARCH

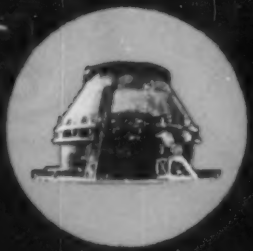
The prevention of cavities in gray iron castings through the scientific selection and location of risers is one of the problems under continuing study by researchers at Case Institute of Technology.

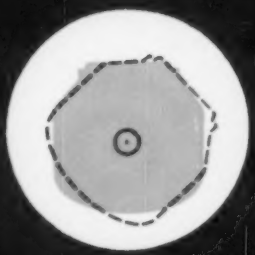
John F. Wallace of Case's Dept. of Metallurgical Engineering is heading the group conducting this American Foundrymen's Society-sponsored research. They have learned that the phosphorus content of the gray iron being cast must be low to prevent the formation of microporosity. The riser itself (a riser is a small container which opens into the casting and is filled with extra metal to prevent cavity formation or depression) must be of adequate size to provide for any expansion of the mold cavity. The research group also has worked on general design of risers themselves.

Grain size reduction also is coming under the scrutiny of the research team. Working with copper, steel, and aluminum, one such method involves vibrating the metal as it solidifies, using ultrasonic tech-

(Continued on page 506)

in oxygen converters . . .





YOU GET FAR MORE
THAN THE VESSEL
FROM PECOR

Top: 110-ton capacity furnace (L-D) with PECor-engineered smoke hood and post crane, at McLouth Steel Corporation.

Center: World's largest oxygen furnace (L-D) during assembly, for Jones & Laughlin's Cleveland Works.

Bottom: All PECor drives are soundly made for assured trouble-free service.

QUALITY in design and manufacture, reflecting unique experience and constant contact with operating L-D installations. Precision engineered auxiliaries!

RELIABILITY, equipment that "stays on the line" making steel.

SERVICE, including *immediate response* to field requirements, with service as close as your telephone.

May we consult with you in the planning stage?

Pennsylvania Engineering CORPORATION NEW CASTLE, PA.

Sales Representatives: Wooldridge Company, Burlingame, Calif.
Fred Middleton Co., Inc., Birmingham, Ala.

BUILDER OF AMERICA'S FIRST 15 OXYGEN CONVERTERS

At the Houston works, Sheffield Division, Armco Steel Corporation, two 20-foot Lectromelt furnaces contribute high availability, accurate control and fast turn-around to volume production of high quality steels. For recommendations on furnace equipment for melting or smelting, get in touch with Lectromelt, world's largest manufacturer of electric furnaces exclusively. Lectromelt Furnace Division, McGraw-Edison Company, 326 32nd Street, Pittsburgh 30, Pennsylvania.

WHEN YOU MELT... Lectromelt McGRAW-EDISON

hot strip rolling on

MORGOIL BEARINGS

MORGOILS were first installed in 1947 on only four stands of the hot strip mill at Weirton Steel Company, a Division of National Steel Corporation. Other backup roll bearings have been discarded and all eleven stands of the rebuilt mill are now rolling high quality strip on MORGOILS.

MORGAN CONSTRUCTION CO., WORCESTER, MASSACHUSETTS

ROLLING MILLS • MORGOIL BEARINGS • GAS PRODUCERS
WIRE MILLS • EJECTORS • REGENERATIVE FURNACE CONTROL

MB 15

HARBISON-WALKER FURTHER ADVANCES PROGRESS IN BASIC OXYGEN STEEL VESSEL REFRACTORIES

Beginning with the introduction of the oxygen steelmaking process in the United States, Harbison-Walker refractories—developed particularly for the linings of these vessels—contributed appreciably to its successful operation. These unique refractories, OXILINE H brick (former name H-W 17-56) and H-W OXIMIX, most widely used, now have been produced commercially for longer than four years.

As the tonnage made in oxygen steel vessels continues to grow, Harbison-Walker refractories increase in the specific kinds and qualities needed for most economical service. Additional brands briefly described in the following are OXILINE CL and OXIBAK. With these various special refractories used under the most severe conditions, the service-life curve of the linings continues its trend upward.

OXILINE H (former name H-W 17-56) is the special tar-bonded basic brick which forms complete working linings with which many excellent records have been made.

OXILINE CL (former name H-W 22-57) is the stabilized tar-bonded basic brick of high magnesia content which is highly resistant to deterioration in storage on exposure to normal atmospheric humidity and carbon dioxide. This working-lining refractory now in service at several plants is giving excellent results.

OXIBAK is a modification of H-W MAGNESITE brick which is used as the fixed, protective lining against the shell. This hard-fired basic brick of high magnesia content is especially suitable for this application because of its good resistance to erosion and spalling.

H-W OXIMIX is the basic ramming mix which forms both the monolithic hearth of the furnace and the intermediate monolith between the OXILINE brick of the working lining and the OXIBAK fixed lining against the shell.

The lining here illustrated shows brands pioneered by Harbison-Walker which continue giving superior service.

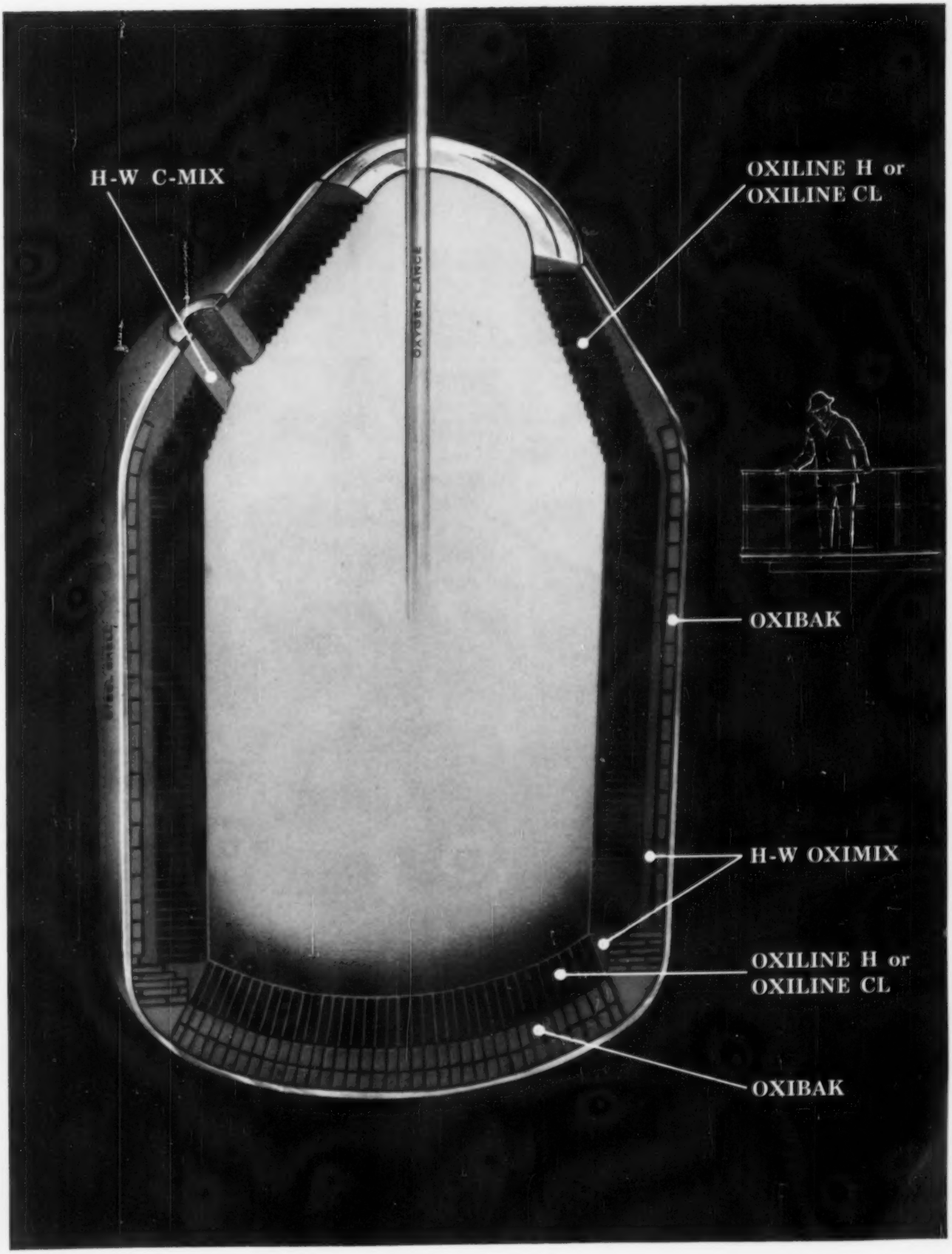
World's Most Complete Refractories Service

HARBISON-WALKER REFRACTORIES COMPANY

AND SUBSIDIARIES

GENERAL OFFICES: PITTSBURGH 22, PENNA.

HW 60-16


H-W C-MIX
OXILINE H or
OXILINE CL
OXIBAK
H-W OXIMIX
OXILINE H or
OXILINE CL
OXIBAK

Authoritative books for engineers

NONDESTRUCTIVE TESTING HANDBOOK

This new pioneering Handbook covers all the means of testing the essential properties and performance capabilities of materials, parts, components, and structures *without impairing serviceability.*

Explains and illustrates applications, advantages, limitations of 24 different test methods applicable in every branch of engineering and industry. Specifications, equipment costs, hundreds of pages of test interpretation data. *Prepared under the auspices of the Society for Nondestructive Testing. 1,100 illustrations, graphs, tables; 1,910 pp. 106 Contributing, Consulting Editors. Robert C. McMaster, Ed. October, 1959.* 2 volumes, $24

PRODUCTION HANDBOOK

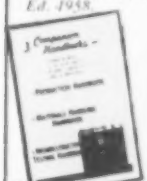
Packed with practical production know-how, this Handbook is the complete key to management-engineering methods that are revolutionizing industrial production today. Fully covers new materials, machines, processes, and proper functioning of company organization.

Supplies proved principles, time- and work-saving systems, and successful operating procedures for maximum productivity at minimum cost. Saves hours of research and costly experimentation. *726 illustrations, tables; 1,726 pp. 48 Contributing, Consulting Editors. Gordon B. Carson, Ed. 2nd Ed., 1958.* $16

MATERIALS HANDLING HANDBOOK

The complete guide to modern materials handling. This unique Handbook explains the governing principles, today's most efficient methods and systems, and recommended equipment for moving material at least cost — whether in raw, in-process, or finished form.

Useful in all industrial situations. Handbook answers every basic question of work flow within and outside the plant. *Sponsored by The American Society of Mechanical Engineers and the American Material Handling Society. 991 illustrations, tables; 1,740 pp. 84 Contributing, Consulting Editors. Harold A. Bolz, Ed.; George E. Hagemann, Assoc. Ed. 1948.* $20



USE THIS COUPON TO ORDER HANDBOOKS OR FREE DESCRIPTIVE BROCHURE

Please send books checked below:

☐ **Nondestructive Testing Handbook,** McMaster, 2 vols. ____ $24
☐ **Production Handbook,** 2nd Ed. Carson ____ $16
☐ **Materials Handling Handbook,** Bolz-Hagemann ____ $20
☐ **Please send free Descriptive Brochure on the above Handbooks.**
☐ Check enclosed ☐ Send C.O.D.
☐ Bill firm ☐ Charge my account

Firm _____
Ordered by _____
Address _____ JM-2
City _____ Zone ___ State _____

THE RONALD PRESS COMPANY
15 East 26th St., New York 10

EDUCATION

(Continued from page 500)

niques as well as sonic ones. When vibration is effective, it results in considerable refinement of the grain of the alloys and improved strength, hardness, and ductility. The application of ultrasonic vibrations to refining grain size in brass is thought to have commercial possibilities, since this metal has not been readily formed by other methods. Similar methods have also been tried on zinc, magnesium, tin, antimony, bismuth, and gray iron.

Development of an as-cast grain refiner for cast steels and copper is being underwritten by Watertown Arsenal in a second phase of grain research. Results so far indicate that adding certain chemicals that do not melt at the high temperatures of molten metal considerably reduces grain size. These unnamed chemicals also are said to reduce separation of elements during the solidification process.

Literature

► A table of estimated weights of cold-rolled strip steel is featured in a new booklet published by Caine Steel Co. It gives approx wt per lineal ft in lb for width from ⅜ in. to 6 in. and for thicknesses of 0.187, 0.120, 0.109, 0.095, 0.083, 0.065, and 0.049 in.

The booklet may be obtained by writing the Caine Steel Co., 5501 W. Grand Ave., Chicago 39, Ill.

► Vanadium Corp. of America has a new booklet entitled *The Stainless Steels.* The booklet covers the development of stainless steels from 1797 to those we use today. Write Vanadium Corp. of America, 420 Lexington Ave., New York 17, N.Y.

► The Cobalt Information Center at Battelle Memorial Institute has prepared a list of commercially available cobalt compounds. The two-page summary lists 46 organic and inorganic compounds, including the new potassium cobalticyanide, and provides information on their uses, formulae, per cent cobalt, molecular weight, specific gravity, crystalline form, melting point, and solubility. Although sources of the compounds are not listed, this information is available from the Center upon request.

Properties and Uses of Commercially Available Cobalt Compounds will be sent to persons addressing requests on company letterhead to the Cobalt Information Center, c/o Battelle Memorial Institute, 505 King Ave., Columbus 1, Ohio. Requesters abroad should write the Centre d' Information du Cobalt, 35, rue des Colonies, Brussels, Belgium.

personals

Ernest Kirkendall, AIME Secretary, was honored by his alma mater Wayne State University during the school's 92nd Alumni Reunion May 14th. Dr. Kirkendall, who received a B.S. from Wayne in 1934, was cited together with three other alumni during the Sheraton-Cadillac Hotel reunion in Detroit. The Alumni Award placed in Dr. Kirkendall's hands was in the form of a framed certificate and separately-bound citation.

Dr. Kirkendall is known for his discovery of the diffusion phenomenon in solid metals now known as the *Kirkendall Effect.* He has previously been honored by the colleges of engineering at the University of Michigan and Wayne State University.

Emo D. Porro is now vice president in charge of marketing for Arnoux Corp., West Los Angeles, Calif. He was formerly general manager of Arnoux's Astra Technical Instrument Corp. div.

Armin F. Fick has been named assistant manager of Western Electric Co. Inc.'s Omaha, Nebr., works. Mr. Fick, who joined Western Electric in 1941, was most recently assistant engineer of manufacture for Western Electric Co.

George A. Timmons and **George P. Halliwell** were given Awards for Scientific Merit by the American Foundrymen's Society during its recent meeting. Mr. Timmons, vice president, Climax Molybdenum of Michigan, Ferndale, Mich., was honored for his services to the Society and to the ferrous foundry industry. Mr. Halliwell, director of research, H. Kramer & Co., Chicago, was recognized for his achievements in brass and bronze casting.

William Chynoweth and **George E. Smith** were among recent promotions in the Union Carbide Metals Co. management. Mr. Chynoweth has been appointed to the staff of the Process Development dept. for special assignments in the Union Carbide div. in connection with electric furnace work.

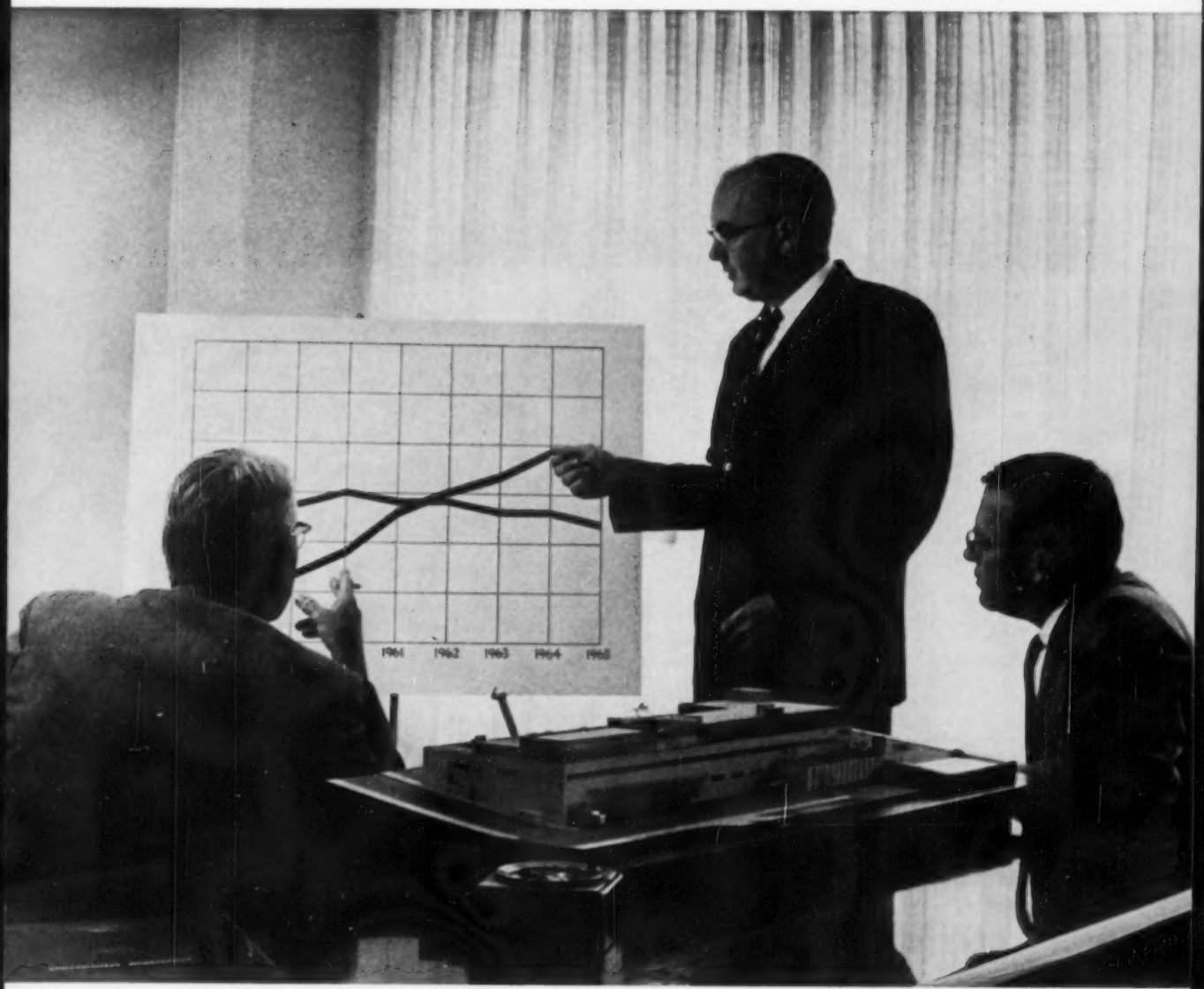
Mr. Smith is now a salesman in charge of the Co.'s Detroit office. He was formerly in the Cleveland district.

Fred L. Siegrist has become assistant editor of *Metals Progress,* American Society for Metals' publication. Previously, he was training supervisor for ASM's home study school div.

Ernest F. Nippes, professor of metallurgical engineering, Rensselaer

(Continued on page 518)

Pre-Engineering by **KAISER ENGINEERS** answers basic plant expansion questions...



Profitability?

Faced with the decision to expand your plant facilities, you should first determine whether all elements combine to form a pattern of future profitability. Independent analysis of all aspects of your proposed program is the *Pre-Engineering* service offered by Kaiser Engineers. The studies and evaluations furnished by KE Pre-Engineering represent only one phase of total KE services. Kaiser Engineers designs and builds for the Steel industry...offers skilled experience in all types of facilities from raw material plants to finishing mills. From Pre-Engineering through design and construction, Kaiser Engineers provides complete one-company service and ingenuity based on years of experience.

KAISER ENGINEERS **KAISER ENGINEERS** engineers-contractors
Contracting since 1914

Oakland 12, Calif. — Chicago, New York, Pittsburgh, Washington, D.C.
Accra, Buenos Aires, Montreal, New Delhi, Rio de Janeiro, Sydney, Vancouver, Zurich

6329-6

PROGRESS REPORT

STORA-KALDO OXYGEN STEELMAKING DEVELOPMENTS

In England, the Consett Iron Company Limited recently announced plans to install two 110-ton Stora-Kaldo convertors . . . in France, Sollac (Societe Lorraine de Laminage Continu) began operating their new 110-ton Stora-Kaldo converter in April . . . in Oxelosund, Sweden, another facility with 110-ton vessels will start production early in 1961 . . . in Domnarvet, Sweden, installation of converters of comparable capacity has been programmed.

The original 30-ton facility at Domnarvet has passed the three-hundred-thousand-ton mark. Steelmakers from the United States have witnessed production, by this process, of a wide range of grades of carbon steel—1005 to 1095—without recarburization. The specified steel chemistry and tapping temperatures were met exactly. Slabs and ingots were shipped to the United States and processed into finished products, ranging from deep-drawing material to cutlery stock. Comments from ultimate users ran from "good" to "the best material we ever had."

These events and the facts detailed below are causing more and more steel producers to take a close, hard look at the Stora-Kaldo process:

FACT NO. 1. What is believed to be the largest single heat—122 tons—ever produced in a basic oxygen converter of any type was produced by Sollac with its Stora-Kaldo facility (23 cubic feet of furnace volume per ton of rated capacity). Consistent heats of 130 tons and more are programmed as this installation reaches normal production later this year.

FACT NO. 2. The ingot yield of virtually every heat at Sollac *has exceeded* 90 per cent since operations started.

FACT NO. 3. Capital costs for a Stora-Kaldo installation are comparable to or lower than competitive processes for equivalent capacity and conditions.

FACT NO. 4. The Stora-Kaldo process is inherently flexible in its ability to produce, within precise metallurgical limits, a wide variety of carbon steels on a heat-to-heat basis—not a "hit or miss" basis—without recarburization and at desired tapping temperatures.

FACT NO. 5. Slag analyses show refractory consumption of 24 pounds per ton of steel, during initial operations of a 110-ton Stora-Kaldo converter, when heat times were considerably longer than normal during crew training programs. This performance substantiates the value of recent lining design developments and assures continuous operation of two vessels in a three vessel plant.

FACT NO. 6. The process can be operated with 96 to 98 per cent purity oxygen to produce steel having a nitrogen content of .003 per cent or less. A typical heat analysis using 99.5 per cent oxygen showed:

	Hot Metal	*Ladle*
C	3.6	.061
Mn	.330	.395
P	1.7	.015
S	.045	.011
N_2	—	.002

FACT NO. 7. Oxygen flow rates currently are 5,000 cubic feet per minute and are being accelerated. Oxygen consumption is approximately 1,950 cubic feet per ton of steel when scrap is used for cooling.

FACT NO. 8. High percentages of scrap and ore can be used for coolant. The thermal efficiency of the process permits scrap addition of up to 50 per cent of total metallics charged. This will produce one and three-quarter tons of steel per ton of hot metal. If ore is used for coolant, approximately one ton of steel is produced per ton of hot metal.

FACT NO. 9. Size of gas cleaning equipment required is modest because carbon monoxide is almost totally burned inside the furnace. The exhaust hood is a simple water-cooled duct. The oxygen lance is a water-cooled pipe which projects through and is connected to the hood. The lance is automatically positioned as the hood is moved into place. Normal lance life is in excess of one thousand heats.

Engineering specialists are available to prepare economic and feasibility studies to help you evaluate the Stora-Kaldo process as it applies to your individual operations. Under United States and Canadian rights granted by Stora Kopparbergs Bergslags Aktiebolag, Sweden, Dravo can furnish complete design, manufacturing, construction and installation of Stora-Kaldo facilities, providing undivided responsibility for the entire contract.

For more information, write or phone Dravo Corporation, Pittsburgh 22, Pennsylvania, EXpress 1-2600.

DRAVO

CORPORATION

—SHARP FOCUS ON BETTER STEEL PRODUCTION

MEMO

TO OXYGEN STEEL OPERATORS!

"virtually no maintenance since start-up on

CHEMICO VENTURI WASHERS"

Where major investments are concerned, performance is vital. At the Algoma Steel Company's new Sault Ste. Marie Basic Oxygen Steel plant, Chemico Venturi washers are exceeding all original performance specifications. Case in point: since start-up in November, 1958, there has been virtually no maintenance on the Chemico washers. This is a normal record for Chemico washers. They are designed to eliminate shut downs for maintenance on gas washing systems, thus making it unnecessary to invest in spare equipment.

Chemico Venturis are paying Algoma other dividends, too, for these washers are operating at better than 98% efficiency. During test periods when operating at 50% over design capacity, the flexibility of the Chemico washers permitted the extra load to be handled without increased washing facilities.

If steel is your business and air pollution your problem, it pays to consider Chemico Venturi washers. You can obtain full information, a copy of a detailed technical brochure, and technical assistance concerning your problem by writing Chemico today.

CHEMICO

CHEMICAL CONSTRUCTION CORPORATION
525 West 43rd Street, New York 36, New York

CHICAGO • DALLAS • HOUSTON • PORTLAND, ORE. • TORONTO • LONDON • PARIS • JOHANNESBURG • TOKYO

Ford has new OH process

Using a combination of fuel and oxygen and substituting burned lime for limestone is expected to reduce by one-half the time required to make a ton of steel by conventional open hearth methods, so says the Ford Motor Co. However, the process is still in the experimental stage cautioned company president, Henry Ford, II, at the firm's annual meeting.

William J. Reilly, general manager of the company's steel div., said that "As we gained experience with oxygen during the past several years, we began to experiment with oxygen-fuel lances through which both the fuel and oxygen are introduced to produce extremely high temperatures. To the best of our knowledge, no other steelmaker has installed these lances in the process."

Continuing, Mr. Reilly said, "These developments led George Ferris, manager of our open hearth furnaces, to consider how the entire process might be hastened even more with the extra heat available. Mr. Ferris reasoned that, if burned lime were used instead of limestone, it, together with the oxygen, should make even more heat available and hurry the process along without risk of mass freezing of the furnace.

"He charged our 200-ton furnace with burned lime and scrap, with the oxygen fuel lance in operation. As soon as the initial charging process was completed, he added the molten iron. This was done about ½ hr after the start, rather than 2 or more hours later. He then shut off the fuel in the oxygen-fuel lances, allowing the conventional end-firing burners, the heat-producing chemical reaction of the ingredients, and the continuous flow of oxygen to refine the steel. In less than 3 hr, 200 tons of high-quality steel were tapped."

The furnace averaged more than 60 tph in the experimental series—compared to 30 tph previously. They also tried the new technique on a 400-ton open hearth equipped with oxygen lances, and got yields of 100 tph, compared to 40 tph using normal oxygen practices.

There are some problems which have to be solved before the process can be used on a commercial basis, however. One factor is the heat of the flame created by the gas-oxygen mixture. This 5000°F temperature may shorten the life of furnace refractories. It is also questionable whether the heat could be maintained throughout the entire steel refining process.

LD steel's future

Production of some 25 million metric tons of LD steel by 1965 is predicted by the managing director of Vereinigte Osterreichische Eisen und Stahlwerke/AG (VOEST). The present annual production rate of 9.15 million metric tons will be augmented by construction of further LD works with a combined capacity of 15.6 million metric tons, he pointed out. Referring to VOEST's collaboration with Krupp, Herr Hitzinger announced that both firms were presently working on 30 LD projects, with at least two being completed annually.

U.S. Steel plans Wyo. mine

When completed in 1962, a Wyoming mining and beneficiating facility will help stoke the blast furnaces of U.S. Steel Corp.'s Geneva works near Provo, Utah. The ore will supplement the Columbia-Geneva Steel div.'s Cedar City, Utah, plant, which will continue to operate.

Extensive mining, concentrating, and pelletizing operations—known as the Atlantic City Project—will supply pelletized iron ore to the Provo, Utah, integrated works. It is destined to become the highest (8300 ft above sea level), large-scale open-pit iron mining operation in the US. After operations begin, conventional open-pit methods will be used to mine the ore, which contains about 30 pct Fe. Next, the ore will be crushed, then conveyed to the concentrating plant, where it will be magnetically concentrated to more than 60 pct Fe. Ore concentrate will move to the pelletizing plant, and then to the blast furnaces in Utah.

LD in Australia

Broken Hill Proprietory Co. is studying the possible installation of basic oxygen (LD) steelmaking facilities. At present, the Australian firm's output is based on the open-hearth process, but it plans to scrap 14 open hearths at Newcastle and install 200-ton LD vessels by 1962. Steel production will be undertaken at Whyalla about 1964, when 100-ton vessels will be put into operation. At each plant, two vessels will be installed; one for use, and one in reserve.

Oxygen production upped

An increase of 400 tpd in the oxygen producing capacity of Linde Co., div. of Union Carbide Corp., has been announced. Most of the oxygen increase will go to steel producers—among them, Bethlehem Steel Co., National Steel Corp., Republic Steel Corp., U. S. Steel Corp., Colorado Fuel & Iron Corp., Armco Steel Corp., and Detroit Steel Corp.

Rotor steelmaking . . . report

South African Iron and Steel Industrial Corp. (ISCOR) is making strides in rotor steelmaking. A recently-installed 100-ton unit at the company's Vanderbijlpark plant is reportedly exceeding expectations. A similar 100-ton furnace is now being erected at ISCOR's Pretoria plant.

The 49.2 ft-long furnaces revolve between 0.15 and 4 (max) rpm. Each furnace has two interchangeable 100-ton vessels. The blowing time varies from 30 to 50 min, depending on the weight of the charge and the type of steel being made.

* * *

From Oberhausen, Germany, home of the rotor, come reports of lining life of 565 heats. Fettling with sintered tar dolomite is required every nine or ten heats. As much as 40 pct scrap has been used in some heats.

* * *

From Russian sources comes word that a new rotor convertor is to be installed at the Azov-Stal works.

REPORTER

Cornerstone Laid for Engineering Center

Trowel in Hand . . .

"A Hundred thousand miracles . . ." and the cornerstone was laid for the United Engineering Center. Presiding at this solemn event were Andrew Fletcher, president of the United Engineering Trustees, the Honorable Herbert Hoover, and Mayor Robert F. Wagner.

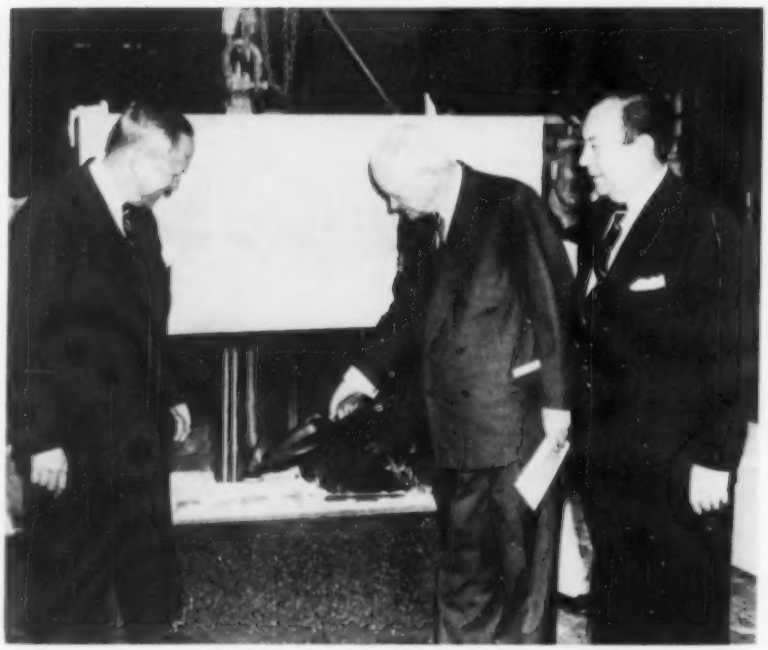
Traditionally, the laying of a cornerstone is both solemn and joyous, with the participants keenly aware that they are taking part in an event by which future civilizations will judge both their character and their nation. Pride also marked the ceremony . . . pride from a job well done, coupled with a knowledge of a share in the future.

"Our tribute today," Mayor Wagner said, "is not to a building because it will enhance the skyline of our city but because it will accommodate a class of professionally-trained men and women who are dedicated with a common unselfish interest, the benefit of their fellow man."

Industry and education, as well as engineers, have contributed toward the United Engineering Center, and "we may be certain that the seed of truth thus spread will take root and produce a hundredfold, thus bringing benefits to industry, advancement to education, and gratification to individual engineers as well as their respective societies."

Mayor Wagner continued, pointing out that although the professions of law and government were older, "the stature and prestige of professional engineering must be preserved and advanced." It is hoped that, "in cementing this symbolic stone, we will have strengthened not only the foundation of a highly significant professional building, but our healthy and dynamic society in which we have implicit confidence to surmount trouble and survive threat, not only during our times but beyond the distant future."

Willis F. Thompson, Vice President, United Engineering Trustees recalled that traditionally the cornerstone of a building contained a box which held documents, relics, and records. In keeping with this tradition, the cornerstone of the United Engineering Center, he said, will contain documents and records from the contributing societies, along with a picture of Herbert Hoover and his "message to posterity".



Andrew Fletcher (left), president of the United Engineering Trustees, smiles his approval as the Hon. Herbert Hoover lays down the first mortar which will anchor the cornerstone of the new building. Looking on is Robert F. Wagner, Mayor of New York City.

Amid a standing ovation, the Honorable Herbert Hoover then strode forward to make a speech to history. "I have been asked to contribute a forecast of what this world may be like when this receptacle is opened one hundred years hence, but mortals were seldom equipped with the gift of prophecy. And the past records of prophets are not too reassuring . . .".

All we can say with assurance is "that the progress of the world in the last hundred years has come from free and productive minds in the civilized part of the world—that is, the nations possessed of independence and personal freedom. If these freedoms be preserved, they will bring more and more discoveries into the fundamental forces in the Universe. And then the engineers will apply these discoveries to the release from less important tasks and bring more comforts to mankind."

During the last century, our profession of engineering has advanced from the status of a trade to a great profession, ranking with all other great professions. And with the training required for an engineer, a great contribution for the future has come to the world. The very nature of training for our profession demands intellectual integrity and minds to whom truth has become an instinct. The leaven of this sort of mind will contribute to continuing progress in the free world."

Mr. Hoover then made his way to the cornerstone, scooped a trowel of cement from a nearby basin and set the stone in place.

A brief benediction then finalized the ceremonies.

METALGRAMS

UNION CARBIDE METALS

. . . news of "Electromet" ferroalloys and metals

JULY 1960

NEW LOOK IN FERROALLOYS -- Steelmakers are using greater tonnages of the new forms in which certain alloys are supplied by Union Carbide Metals. For example, refined chrome and 75 per cent ferrosilicon are available as convenient pigs that greatly simplify handling. When added to the furnace or ladle, these pigs give higher metallic yield because no fines are lost in the slag. Their use? Refined chrome is used in stainless steel, aircraft and bearing steels, tool steels, and cast iron. 75 per cent ferrosilicon is a popular open-hearth ladle addition, particularly in electrical steels.

* * *

UNIT-WEIGHT PACKAGES GROW -- A popular packaging feature of many "Electromet" alloys is unit-weight cans and bags. Containing exact weights of alloying elements, these packages provide accurate alloy additions simply by counting out the number of packages required. "Chromtemp" exothermic ferrochrome and "Mantemp" exothermic ferromanganese -- highly efficient ladle addition alloys for open-hearth steels -- are packed in unit-weight cans. So are self-reducing tungsten and self-reducing vanadium, economical alloys for tool and constructional steels. Also, 17 "Electromet" alloys are available in unit-weight bags.

* * *

FORMS PROCESSED IN A VACUUM -- Other alloy forms include bricks and pellets of "Simplex" ferrochrome, a widely used low-carbon ferrochrome for stainless steel. These convenient forms are available because the alloy is vacuum-processed to drive carbon down to extremely low levels. Having the lowest carbon content of any ferrochrome available, the alloy aids stainless melters in meeting low-carbon specifications. Also, "Simplex" ferrochrome penetrates the slag and dissolves readily. As an aid to handling, storage, and inventorying, the bricks are packed in new pre-weighed steel-strapped bundles.

* * *

AT YOUR SERVICE -- Improved alloys and packaging techniques are under constant study at Union Carbide Metals. Experienced materials-handling representatives work directly with metal producers to help determine the most efficient and economical types of alloy packaging and handling in individual plants. Their recommendations on traffic, handling, storage, and usage often result in big savings in money, time, space, or material.

* * *

NATION-WIDE FACILITIES -- To meet the demand for a wide variety of alloys and metals, Union Carbide Metals maintains an efficient warehouse and distribution network to serve metal producers throughout the country. Stocks are maintained at 6 plants and 26 warehouses conveniently located near major metal-producing centers. Rail, truck, barge, and boat shipments speed products to customers' plants. Your Union Carbide Metals representative will be glad to give you further information about the products and services described above. Ask for the article, "Electromet Alloys...When, Where, How You Need Them," in the Winter 1959 issue of UNION CARBIDE METALS REVIEW.

* * *

UNION CARBIDE METALS COMPANY, Division of Union Carbide Corporation, 270 Park Avenue, New York 17, N. Y. In Canada: Union Carbide Canada Limited, Toronto.

"Chromtemp," "Electromet," "Mantemp," "Simplex," and "Union Carbide" are registered trade marks of Union Carbide Corporation.

letters

to the editor

Electron Beam

In the May issue of JOURNAL OF METALS there is an article by C. M. Adams on *Electron Beam Welding* (p. 410).

Professor Adams implies that at voltages between 15,000 to 30,000 volts fusion zone shapes similar to those produced in permanent electrode arc welding are obtained, and that deep, narrow welds are produced only by very high voltage equipment.

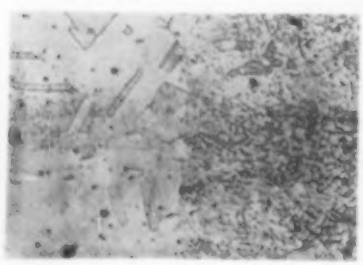
The attached photomicrographs of welds made in our laboratory at 25,000 volts demonstrate that at least a 4:1 depth to width ratio can be obtained at relatively low voltages.

We would appreciate it if you would inform your readers of this recent development.

Marsbed H. Hablanian
Chief Development Engineer
NRC Equipment Corp.

Electron beam welded at 25,000 v . . .

Top and right, Type 347 stainless macro-etched in saturated solution of ferric chloride in aqua regia. 6X. Below, 347 stainless microetched electrolytically in 10 pct oxalic acid solution. 250X.



Re: English vs Metric System

This action comes from your invitation in the April issue of the JOURNAL, p. 276, to express thoughts concerning the above comment.

Measuring systems are engineering tools, and the units by which measurements are expressed constitute a shorthand means of communication. The traditional origins may have nostalgic values, but when they become cumbersome and time consuming in interpretation, application, and communication, they should be replaced to save time and promote efficiency. Generation after generation is burdened with the poorly related English terminology and makes them victims of an obsolete system for measuring time, temperature, dimensions, weight, volume, and so forth.

The revision should not be a temporizing procedure such, for example, as the term *micro inch;* nor should the mixed-up British version of tons per square inch per °C be allowed to obtain a foothold.

It would matter little whether the meter is 1 ft long, 3 ft, or 5 ft, just as long as its standard dimension is internationally agreed upon and stabilized for a 10, 20, or 99-year term. The decimal system would take care of the rest.

Since time is pressing upon engineering schools and graduates to accomplish more in less time, a first step toward speeding up the change should begin with the 1960 freshman college engineering classes.

It is certain that some expense and confusion, as well as delay, is inevitable for a change of this magnitude, but since its objective is desirable for the long term, its accomplishment should be achieved as completely as possible.

It should be fully supported by the Government, as well as engineering societies such as the National Academy of Sciences and Engineers Joint Council, for example. A Government decree would serve this purpose best, but since this might seem dictatorial, a milder approach by way of the Government purchasing all its requirements through metric specifications and standards would quickly lead the Country toward adoption of the metric system.

We should not wait for India and Japan to show us the way.

James S. Vanick
Consultant, The International Nickel Co. Inc.

Rocky Mt. Minerals Conference to Meet at Salt Lake Oct. 5-7

The Sixth AIME Rocky Mountain Minerals Conference is scheduled for the Newhouse Hotel in Salt Lake City, Oct. 5-7.

The program will consist of five technical sessions, with papers on such subjects as fused electrolysis . . . rock mechanics . . . reagent system design . . . undersea mining . . . and the role of microorganisms in the leaching process. An exploration symposium also will be held, with discussions of what constitutes exploration, the cost of exploration, and Canadian vs American exploration practices. Final event of the three-day meeting will be a field trip to Hercules Powder Col.'s new *Minuteman* missile research plant at Bacchus, Utah.

Sponsor for the Conference is the Utah section of AIME. J. M. Ehrhorn is the Conference's General Chairman; H. E. Wright is Asst. General Chairman; A. Soderberg is in charge of Program; J. L. Peterson, Arrangements; J. E. Van Stone, Entertainment; R. L. Stewart, Publicity; and Mrs. A. J. Thuli, Ladies Events.

Corrosion Complaints On 316L Stainless Sought by Welders

The High Alloys Subcommittee of the Welding Research Council would like to receive any complaints involving 316L weld metal.

Service exposure of Type 316L stainless steel in the as-welded condition seems to lead to weld corrosion under a variety of conditions. However, too little information has been published to permit prediction of this attack.

The Subcommittee is soliciting information about any such experience. A post card addressed to the WRC High Alloys Subcommittee, 1500 S. 50th St., Philadelphia 43, Pa., will initiate the correspondence necessary to explore the conditions under which the weld corrosion occurred.

AIME OFFICERS

Joseph L. Gillson	President
Howard C. Pyle	Past-President
R. R. McNaughton	President-Elect
George I. Brigden	Treasurer
Ernest Kirkendall	Secretary

VICE-PRESIDENTS

John Chipman	Basil P. Kantzer
John P. Hammond	S. D. Michaelson
Walter R. Hibbard	J. W. Woomer

DIRECTORS

J. B. Austin	James C. Grey
Herbert F. Beardmore	Wayne E. Glenn
John S. Bell	Elmer A. Jones
Richard C. Cole	Earl M. Kipp
A. B. Cummings	C. C. Long
R. H. Felerabend	J. S. Smart, Jr.

THE METALLURGICAL SOCIETY OF AIME

C. C. Long	President
John Chipman	Past-President
J. S. Smart, Jr.	Vice President
T. D. Jones	Treasurer
R. W. Shearman	Secretary

BOARD OF DIRECTORS, THE METALLURGICAL SOCIETY

H. B. Emerick	R. R. McNaughton
R. W. Farley	T. A. Read
K. L. Fetters	J. H. Scaff
J. J. Golden	A. W. Schlechten
W. J. Harris, Jr.	R. Schuhmann, Jr.
J. H. Hollomon	J. D. Sullivan

SOCIETY PUBLICATIONS COMMITTEE

D. J. Carney, Chairman

J. H. Hollomon	D. L. McBride
J. H. Jackson	W. O. Philbrook
H. H. Kellogg	J. S. Smart, Jr.
T. B. King	R. L. Smith
F. C. Langenberg	J. D. Sullivan
R. Maddin	F. L. Vogel

Advisory Subcommittee

J. H. Jackson, Chairman

D. J. Carney	H. H. Kellogg, Jr.
J. F. Elliott	A. E. Lee, Jr.
J. R. Freeman, Jr.	E. R. Morgan
B. W. Gonser	T. O. Paine
J. D. Hanawalt	T. A. Read
J. J. Harwood	A. J. Shaler

V. F. Zackay

editorial

Basic Oxygen Steelmaking

This month the JOURNAL OF METALS takes pride in presenting a comprehensive summary of developments taking place in the basic oxygen steelmaking processes. With a world-wide tidal wave moving these new processes forward, we felt that, while you might not be overly concerned with such problems as the treatment of high-phosphorous hot metal, you would nevertheless be interested in noting the adaptation of basic oxygen steelmaking to difficult-to-solve steelmaking problems in many countries.

In this issue, you are directed to the history of the LD process, the place of basic oxygen steelmaking, the physical chemistry of the process, a summary of dust control procedures, and then some words about specific problems, processes, and plants. We have included both the LD and the Kaldo processes, as well as such variations as the LD-AC process, and a new Canadian bottom-blowing process. We regret the lack of an article on the Oberhausen Rotor process, but with the recent start-up of operations in South Africa, perhaps new information will soon be available on this process. In the meantime, we call your attention to the article, *Rotor Steelmaking Process*, by Graef et all on pp. 1425-1439 of the November 1957 issue of JOURNAL OF METALS.

We hope to make this special issue on Oxygen Steelmaking an annual event, since the rapid strides being taken by these processes would seem to call for it.

But for our readers in others areas of metallurgy, be assured that we have not forgotten you and are even now planning several special issues for your areas of metallurgy later in the year. FWS

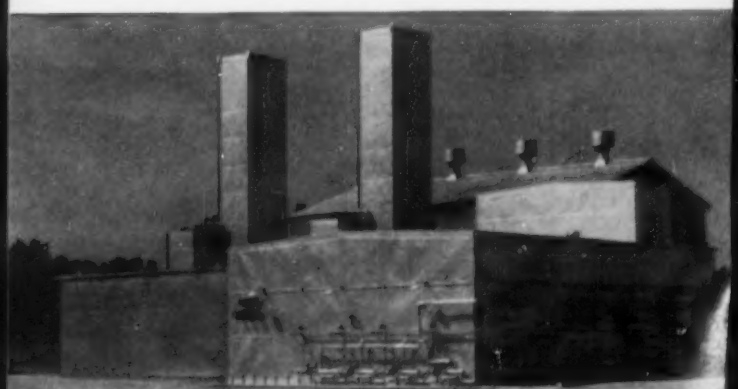
HOW ACME STEEL MADE HISTORY

WITH OXYGEN

In mid-1959, when the first heat was poured at Acme Steel Company's new 35 million dollar plant at Riverdale, Illinois, steel was made for the first time in North America by the combination of continuous hot blast cupolas and top blown oxygen converters. New speed and economy were brought to the production of high quality steel . . . and Acme's finishing mills were assured a supply of ingots at lower cost to serve an expanding list of customers.

A striking highlight of Acme's accomplishment is that just a few years ago the company did not produce any of its own steel! Semi-finished steel for its hot and cold rolled products was all purchased, subject to constantly changing prices and delivery schedules. When the company planned to integrate its operations, a key factor was a reliable, low-cost supply of high purity oxygen for the converters. Acme called on Air Products for engineering and cost studies, and made the decision. As a result Air Products installed directly adjacent to the mill a generating facility that can supply Acme with more than 80 million cubic feet of high purity oxygen per month, at no capital investment to Acme. Acme's converters get all the oxygen they need at the low cost that makes this new process feasible.

Helping American industry put gases profitably to work has been Air Products business for over 20 years. Air Products developments have reduced the cost of bulk oxygen by 80% . . . turned many so-called "waste gases" into valuable new sources of raw materials . . . provided industry with continuous tonnage quantities of pure oxygen, nitrogen, argon, helium, hydrocarbons and synthesis gases. If your plans hinge on a dependable, low-cost supply of these or other gases, we are ready to give you facts and recommendations that make sound business sense. Air Products, Inc., Allentown, Pa.



Air Products oxygen facility supplying Acme Steel Co.

Air Products
...INCORPORATED

RESEARCH METALLURGISTS

The continual expansion of our central Research Laboratories offers a rich opportunity for qualified professional metallurgists, MS Ph.D. The highly diversified product line of this established, progressive corporation provides opportunity for company-sponsored metallurgical research of almost unlimited variety and scope. Personal interest, initiative, and achievement are recognized in a work environment designed to maximize individual freedom and opportunity.

Write, giving details of educational background and prior work experience to:

J. T. Jarman
Assistant to Vice President
in Charge of Research
Allis-Chalmers Mfg. Co.
Milwaukee 1, Wisconsin

STEEL STEEL STEEL STEEL STEEL

RESEARCH METALLURGISTS

Continuing a program of gradual expansion of facilities and personnel, the J&L Research Division is interested in employment inquiries from engineers who are considering an employment change now or in the near future. Plans have recently been approved to make a significant addition to laboratory and shop space within the next year.

Openings presently exist in the following areas: process metallurgy, physical metallurgy, metal working, corrosion, alloy development, electrical steels, ore beneficiation and agglomeration.

Inquiries are welcomed from men with Ph.D., M.S. or B.S. degrees, with or without industrial research experience. When it appears to be mutually desirable, interviews are arranged in Pittsburgh.

Excellent opportunity exists for professional development and personal advancement in the research field or in technical functions related to production and sales. Continuation of education through attendance at evening classes at Carnegie Institute of Technology and the University of Pittsburgh is encouraged by the J&L Educational Assistance plan.

If you are interested, send a complete resume in confidence to

J. A. Hill
RESEARCH AND DEVELOPMENT DEPARTMENT
Jones & Laughlin Steel Corporation
900 Agnew Road, Pittsburgh 30, Pennsylvania

PERSONALS

(Continued from page 506)

Polytechnic Institute, has been elected Director-at-Large of the American Welding Society.

Eugene A. March is now the director of metallurgy for Crucible Steel Co. of America. Mr. March was formerly assistant works manager at the Co.'s Midland, Pa., plant.

Pierre E. Coheur has been named administrative manager of the Centre National de Recherches Métallurgiques, of Belgium. The appointment followed the announcement that the Centre's Charleroi and Liege sections have been united. Administrative services for the combine will be carried out at Abbaye du Val-Benoit.

P. S. Weaver and **Samuel Naismith** are among recent U.S. Steel Corp. appointments. Mr. Weaver, a U.S. Steel employee since 1933, is now assistant vice president—appropriations. Mr. Naismith, formerly analysis engineer in the facility planning dept. of engineering and research, has taken the post of vice president—facility planning.

Carleton S. Harloff, president of Phelps Dodge Refining Corp., has been elected a director of the Long Island Railroad and a trustee of the Ridgewood, N. Y., Savings Bank.

John C. Fisher has been appointed to the Mechanical Engineering Advisory Committee in the University of Rochester's College of Engineering. Dr. Fisher is a research metallurgist in the Physical Metallurgy section, General Electric Research Laboratory.

International Nickel Co. Inc.'s annual organization meeting of the board of directors resulted in a series of new appointments.

Albert P. Gagnebin and **Ralph H. Waddington** were elected vice presidents of The International Co. of Canada Ltd.

John A. Marsh, vice president of The International Nickel Co. Inc., was elected to the further office of president of the Huntington Alloy Products div.

In other appointments, **L. E. Grubb** became vice president—sales and **E. M. Kline**, vice president—operations, both in the Huntington Alloy Products div.

Paul Queneau, Past-Chairman of the Extractive Metallurgy Division's Copper, Nickel, and Precious Metals Committee, has been named technical assistant to the president, The International Nickel Co. of Canada Ltd.

G. J. Brittingham has completed his assignment with the United Nations Korean Reconstruction Agency and

(Continued on next page)

PERSONALS

(Continued from previous page)

is again available for consulting in nonferrous extractive metallurgy. He has returned to London.

Donald F. Rundle is now manager of metallurgical development at Climax Molybdenum Co.'s Chicago field office. The Co. is a division of American Metal Climax Inc. Formerly managing engineer of Chrysler Corp.'s metallurgical research department, Mr. Rundle will now coordinate developments involving molybdenum alloy irons and steels in the tractor, oil field equipment, and railroad industries.

Clyde Williams, former AIME President and one of the organizers of The Copper Products Development Association (CPDA) addressed the Copper and Brass Research Association on *The Renaissance in Copper* recently.

Dr. Williams cited the following projects that CPDA plans to undertake or has under consideration:

1) Development of a stainless copper, possibly by metallurgical surface treatment;

2) Development of organic and inorganic protective finishes for copper, brass, and bronze;

3) Development of abrasion-resistant plastic finishes for copper products and combinations of copper with the newer plastics and glasses to give materials of superior properties and great esthetic appeal;

4) Increased uses for copper in cast iron and as an alloying element in steel;

5) New copper-base alloys of unusual properties and utility;

6) Combinations of copper and aluminum for electric power applications;

7) New uses in construction and in the transportation industries; and

8) The development of copper chemicals for use in industry and agriculture.

The growing acceptance of electric-drive for trucks and construction machinery indicates that electric-drive automobiles may not be too far off, Dr. Williams noted. An electric motor at each drive wheel and the necessary generating equipment could boost copper consumption, he predicted. The field of marine technology is another major outlet for copper.

William J. Killian and **Harry E. Orr** have been promoted by the Vanadium Corp. of America. Mr. Killian moves up from assistant manager to manager of the Pittsburgh district. Mr. Orr relinquished the managerial post in order to devote full time to being commercial vice president of engineering sales.

Robert F. Mehl has been awarded the Platinum Medal given by the Institute of Metals (UK). Dr. Mehl, currently on leave from Carnegie Institute of Technology as European scientific liaison for the U. S. Steel Corp., was cited for his contributions to nonferrous metallurgy.

George H. Wagner, director of research for the Linde div., Union Carbide Corp., was recently awarded the 1960 Schoellkopf Medal for contributions in research and chemistry. The Medal is awarded by the Eastern New York section of the American Chemical Society.

Jack B. Freeman has been appointed Eastern District sales manager of Materials Research Corporation Manufacturing Corp. In his new position he will supervise East coast sales of MRC's line of zone refiners, high-vacuum furnaces, and other equipment.

METALLURGISTS

PHYSICAL CHEMISTS

For composite materials research...

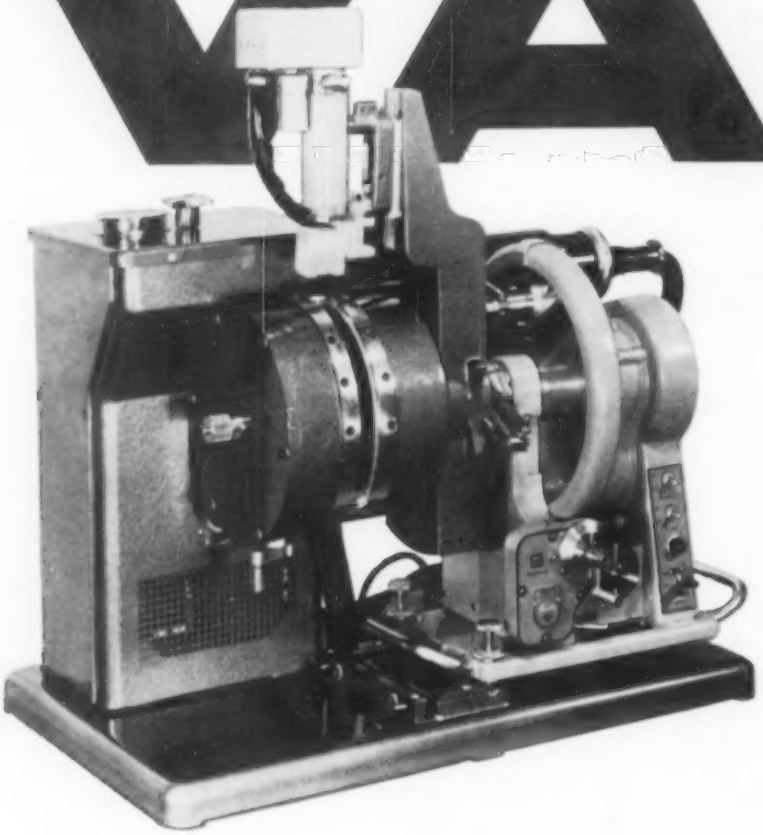
The Lewis Research Center, NASA, is expanding its materials research effort, particularly in the field of composite materials for use at advanced temperatures and in unusual environments. Metallurgists and Physical Chemists, preferably with advanced degrees, and with experience in powder metallurgy are needed to plan and perform basic and applied studies of composite materials involving refractory metals—oxide and analogous systems.

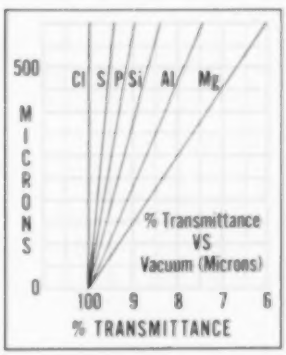
Fully equipped research facilities both for forming and evaluation of experimental materials are available. These include the latest vacuum, melting, sintering, swaging and extrusion apparatus. Equipment for detailed studies of the mechanical and physical characteristics of experimental materials includes X-ray diffraction, electron microscope, emission spectrograph and elevated temperature vacuum tensile and stress-rupture apparatus.

Send resume to: Placement Officer
National Aeronautics and Space Administration
Lewis Research Center
21000 Brookpark Road
Cleveland 35, Ohio

NASA National Aeronautics and Space Administration

The Big Contribution of VAC in X-ray





In X-ray spectrographic analysis, evacuation of the radiation path results in significantly higher counting rates than those obtained in air or even helium — particularly for the lighter elements magnesium (12) through sulphur (17).

The true value of the Norelco Vacuum Spectrograph lies in the fact that its satisfactory use as a routine laboratory and industrial tool, requires no expert supervision to obtain optimum performance. It can be readily integrated into existing laboratory or industrial conditions to provide dependable data. It is versatile, durable and ideally suited for routine as well as diverse applications.

The graph here illustrated reveals that the percentage of quanta transmittance varies minutely with increases in vacuum below 100 microns, (0.1 mm. Hg.). In terms of efficiency, this degree of vacuum is obtained in *less than one minute* with the Norelco vacuum apparatus — and within this time period, offers ideal conditions for reproducible results which are well within the range of required statistical accuracy.

Write today for more information on this truly versatile addition to your X-ray laboratory.

UUM

Spectrographic Analysis

The Vacuum Spectrograph is universal in the sense that it may be used to provide either evacuated or gas-filled atmospheres.

Two crystals, mounted on a holder in the X-ray path, permit optional choice of either crystal without breaking vacuum — effectively extending the analytical range to all detectable elements.

Two detectors, scintillation and proportional, may be used alternatively or sequentially with either crystal.

PHILIPS ELECTRONIC INSTRUMENTS Norelco

PHILIPS ELECTRONIC INSTRUMENTS

A Division of Philips Electronics and Pharmaceutical Industries Corp.

750 SOUTH FULTON AVENUE, MOUNT VERNON, N.Y.

In Canada: Research & Control Instruments • Philips Electronics Industries Ltd. • 116 Vanderhoof Ave. • Leaside, Toronto 17, Ont.

Management Conf. at Chicago Hotel Sept. 15-16

Managing Tomorrow is the theme of the Eighth Annual Engineering Management Conference, meeting at the Morrison Hotel in Chicago Sept. 15-16. The AIME is one of the seven Society sponsors for the meeting, which will be divided into four parts.

The morning of Sept. 15th will be devoted to a discussion of Impinging Forces. This will set the stage for the two-day Conference by identifying the major forces or influences bearing upon 1) the national welfare; 2) private industry; 3) the availability of raw materials; and 4) resources and technology with which to meet national and industrial needs.

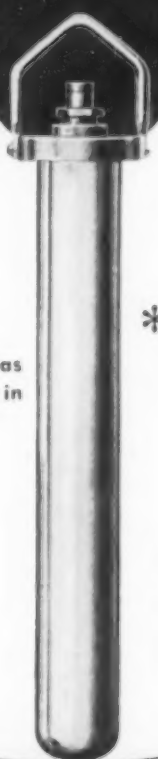
New Requirements and New Aids for Managers is the theme for the afternoon session on Sept. 15th. The session is designed to bring out new demands on managers in terms of forecasting, planning, scheduling, organizing, integrating, and measuring technical work, plus the major advances in using data processing machines.

The third session will be entitled Impact on Professional People. The trend toward more brain work and less muscle work by men will be discussed, as will the long-range and detailed planning, scheduling, integration, and measuring required by mechanization and automatic machine production.

Impact on Education, the theme of the final session, is intended for all engineers who aspire to positions as managers of technical work. Technical schools, business schools, post graduate, and home study will come under discussion.

Among the speakers during the two-day Conference will be Walker Cisler, president of the Detroit Edison Co. and the Power Reactor Development Co. Peter F. Drucker, professor of management, New York University, will address the Conference banquet the evening of Sept. 15th.

NEVER BEFORE
an OXYGEN LANCE
with all these
* FEATURES



* New lance tips, featuring a single connection that permits easy replacement in less than an hour.

* Superior water-cooling extends lance life as much as 100 heats over old style tip.

* Prompt delivery of new lances and replaceable tips from stock.

* Thoroughly proved as standard equipment in large steel mills.

* Fabricated to any length to your specifications by steel mill specialists.

SEND FOR BULLETIN 260

Tells how to lower your downtime and operating costs with Hutton oxygen lances. Write Hutton Fabricating Mfg. Corp., 2736 East 79 Street, Cleveland 4, Ohio. 'Phone EXpress 1-7432.

OXYGEN HUTTON LANCES
OXYGEN LANCES & TIPS • DOORS & FRAMES
SPECIAL STEEL MILL FABRICATION

THE ENGINEERING INDEX

Here is a guide to the current technological literature of the world. More than 1500 bulletins, reports, transactions, and periodicals are reviewed and abstracted to supply engineers with up-to-the-minute developments in their respective fields of interest. Information on a range of 249 subject divisions is classified on 3 x 5 in. cards, then passed on to subscribers to the index service in the form of daily and weekly reports.

You can choose as much or little of the service as you need, at a cost to fit your budget. For a free 16 pp. catalogue listing divisions, prices, and additional information, write:

The Engineering Index, 29 W. 39th St., New York 18.

One of a series

Let's get clear on—
WHAT ENGINEERS DO

Simply stated, engineers apply the sciences to give people use of nature's materials. Voices.

Scientists make it known. Engineers make it useful.

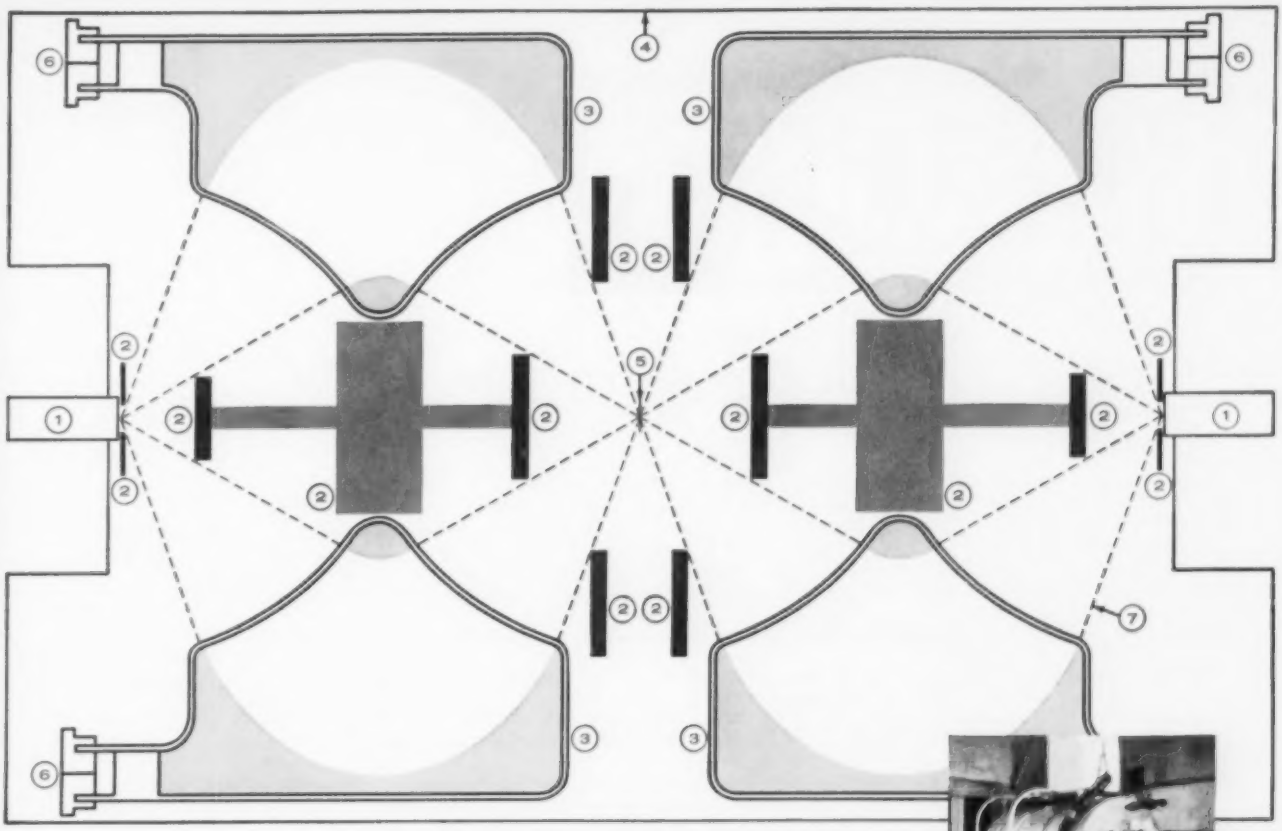
Scientists split the atom; engineers design and build the atomic power plants.

All science knows would benefit nobody if not applied by engineers to manufacturing, construction, mining, agriculture or the generation of power.

These are the great engineered industries all based on scientific knowledge.

Engineers plan, design, produce, maintain and operate. To repeat: Scientists make it known. Engineers make it useful.

Engineers Joint Council
29 West 39th St., N. Y. 18, N. Y.
For information call Pennsylvania 6-8220

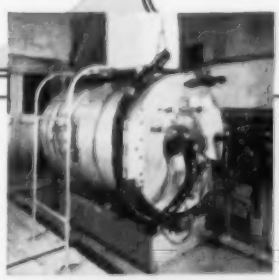


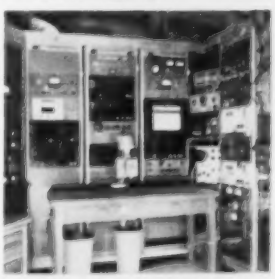
1 Detector, **2** Baffle, **3** Spectrometer Coil, **4** Vacuum Chamber, **5** Beta Radioactive Source, **6** Cooling Water Supply, **7** Dashed lines represent beta-ray trajectories in the instrument.

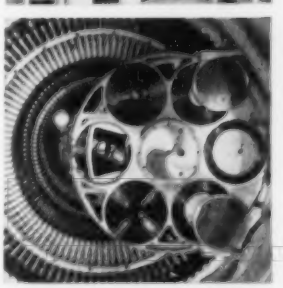
BETA-BETA COINCIDENCE SPECTROMETER

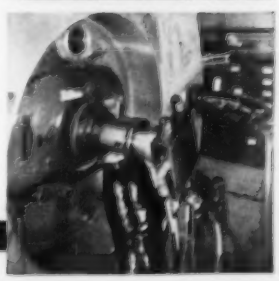
Precisely determined nuclear level energies, their ordering, lifetime, quantum number assignments, and the mode and character of their radioactive decay are some of the raw materials of our understanding of nuclear structure. A powerful new tool for the analysis of complex level schemes . . . the magnetic, iron free, double electron coincidence spectrometer . . . has been designed and built by Argonne scientists. The instrument provides exceptional transmission (~20%—2%) and good resolution (1—0.1%) in each of its independent units. These features, coupled with auxiliary gamma and alpha detectors, also enable Laboratory scientists to study timewise coincidences and angular correlations in electron-electron, electron-gamma and alpha-electron cascades.

Staff positions are available both at the site near Chicago, Illinois and the site near Idaho Falls, Idaho for qualified *physical metallurgists, chemical engineers, physicists, mechanical engineers, metallurgical engineers, chemists, electrical engineers, mathematicians, technical writers.*









Argonne
NATIONAL LABORATORY

Operated by the University of Chicago under a contract with the United States Atomic Energy Commission

Direct Inquiries to:
Louis A. Turner, Deputy Director
9700 South Cass Avenue—Z2
Argonne, Illinois

TRANSACTIONS

OF THE METALLURGICAL SOCIETY OF AIME

Papers Accepted to July 1, 1960

X-ray Studies of Polygonization and Subgrain Growth in Aluminum, by R. J. Towner and J. Alfred Berger (IMD)
The Oxidation of Iron in Carbon Dioxide—Carbon Monoxide Atmospheres, by W. W. Smeltzer (IMD)
The Deformation of Unalloyed Titanium Sheet as a Function of Orientation and Strain Rate, by C. P. Gazzara and E. P. Klier (IMD)
The Effect of Chromium on the Activity of Sulfur in Liquid Iron, by N. R. Griffing and G. W. Healy (ISD)
The Stress-Induced Ordering Internal Friction of Iron-Rich Alloys of Iron and Aluminum, by J. C. Shyne and M. J. Sinnott ((IMD)
Recovery of the High Temperature Creep Properties of Properties of Polycrystalline Aluminum, by W. D. Ludemann, L. A. Shepard, and J. E. Dorn (IMD)
Effect of Stress Upon the Recovery and Effect of Negative Strain Upon the Yield Point of Zinc Single Crystals, by James V. Rinnovatore and Norman Brown (IMD)
Yttrium-Nickel System, by B. J. Beaudry, A. H. Daane (IMD)
Growth Behavior of Cube-Oriented Secondary Recrystallization Nuclei in High-Purity Silicon-Iron, by J. L. Walter and C. G. Dunn (IMD)
The Effects of Stored Energy and Recrystallization on the Creep Rupture Properties of Internally Oxidized Copper-Alumina and Copper-Silica Alloys, by Masao Adachi and Nicholas J. Grant (IMD)
The Interface Temperature of Two Media in Poor Thermal Contact, by G. Horvay and R. H. Edsal (IMD)
Annealing Twins and Coincidence Site Boundaries in High-Purity Lead, by K. T. Aust and J. W. Rutter (IMD)
The Tantalum-Rhenium System, by J. H. Brophy, P. Schwarzkopf, and J. Wulff (IMD)
Dihedral Angle Measurement, by O. K. Riegger and L. H. Van Vlack (IMD)
Mechanical Properties of Tantalum Metal Consolidated by Melting, by M. Schussler and J. S. Brunhouse, Jr. (IMD)
Kinetics of Exchange Reactions Between Liquid Bismuth—Rare Earth Alloys and Fused Salts, by H. M. Katz, F. B. Hill, and J. L. Speirs (EMD)
Hydrogen Precipitation of Nickel from Buffered Acid Solutions, by S. C. Sircar and D. R. Wiles (EMD)
The Effect of Hydrogen on the Mechanical Behavior of Aged Alpha-Beta Titanium Alloys, by R. A. Nadler and D. L. Day (IMD)
The Growth Rate of Bainite, by G. R. Speich and Morris Cohen (IMD)
The Behavior of Composite Silver- Alumina Alloys Above the Melting Point of Silver, by H. R. Peiffer (IMD)
The Role of Stress in Hydrogen Induced Delayed Failure, by E. A. Steigerwald, F. W. Schaller, and A. R. Troiano (IMD)

Join the Metal Man's Society Now!

The Metallurgical Society of AIME
29 West 39th Street
New York 18, New York

Gentlemen:

I am interested in joining The Metallurgical Society. Please send further information and an application for membership.

Name _____

Address _____

Qualified individuals belong to The Metallurgical Society of AIME to insure professional development and identification through active support of the metal man's society.

Maximum service on a basis of technical specialties is achieved through divisional organization. The Institute of Metals Division serves those engaged in developing, economically producing, and applying new alloys.

The importance of Iron and Steel Division activities is reflected in the active support of these activities by men in all phases of the ferrous metals field. A number of ISD meetings have become nationally famous.

The Extractive Metallurgy Division consists of men who work in extraction, smelting, and refining of nonferrous metals. Here, as throughout the Society, a balanced program results in professional growth through membership.

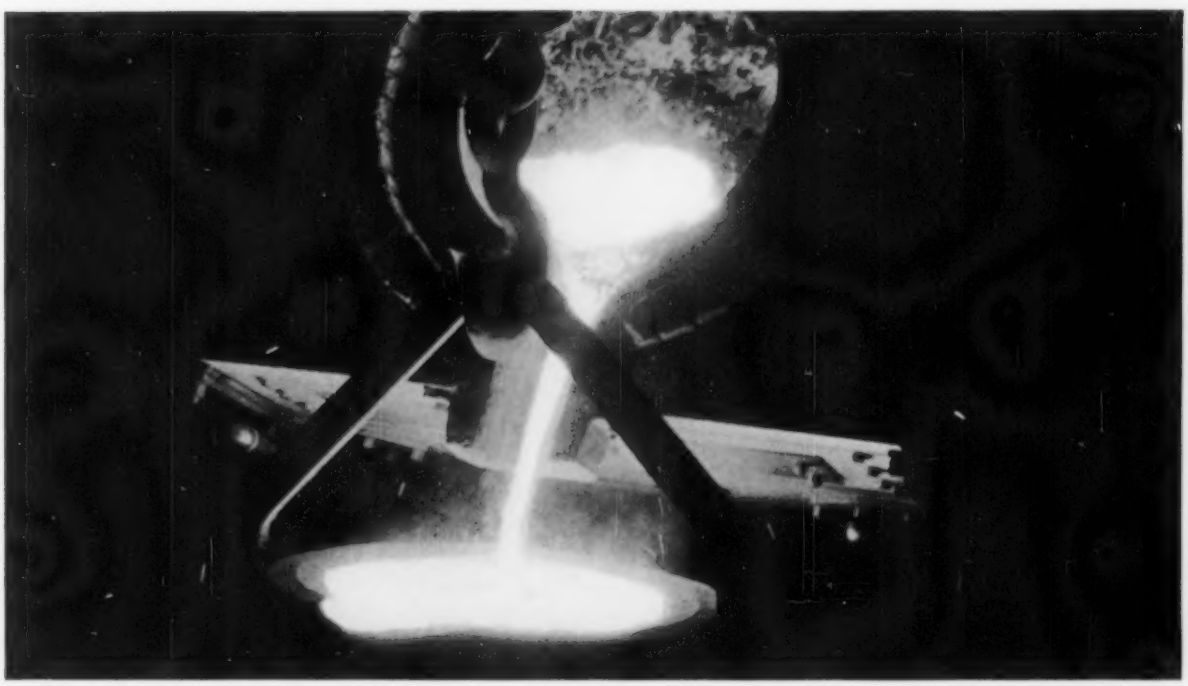
Add life to linings...

Norton MAGNORITE* fused magnesium oxide ramming mix rams easily to high uniform densities that provide extra long service life. Careful grain sizing minimizes segregation. Use wherever high refractoriness, inclusion-free melts, and low outgassing are "musts". Ideal for high frequency melting of alloy steels and high temperature alloys containing nickel/cobalt base; vacuum melting, etc. Proved performance record, in furnaces of all sizes.

Rammed Weight	172 lbs./cu. ft.
Grain Sizing	6F and finer
MgO	91.3%
Al_2O_3	5.2%
CaO	1.7%
SiO_2	1.5%
Fe_2O_3	.2%

For full information on ramming, sintering, etc., write NORTON COMPANY, Refractories Division, 706 New Bond Street, Worcester 6, Massachusetts.

*Trade Mark Reg. U. S. Pat. Off. and Foreign Countries

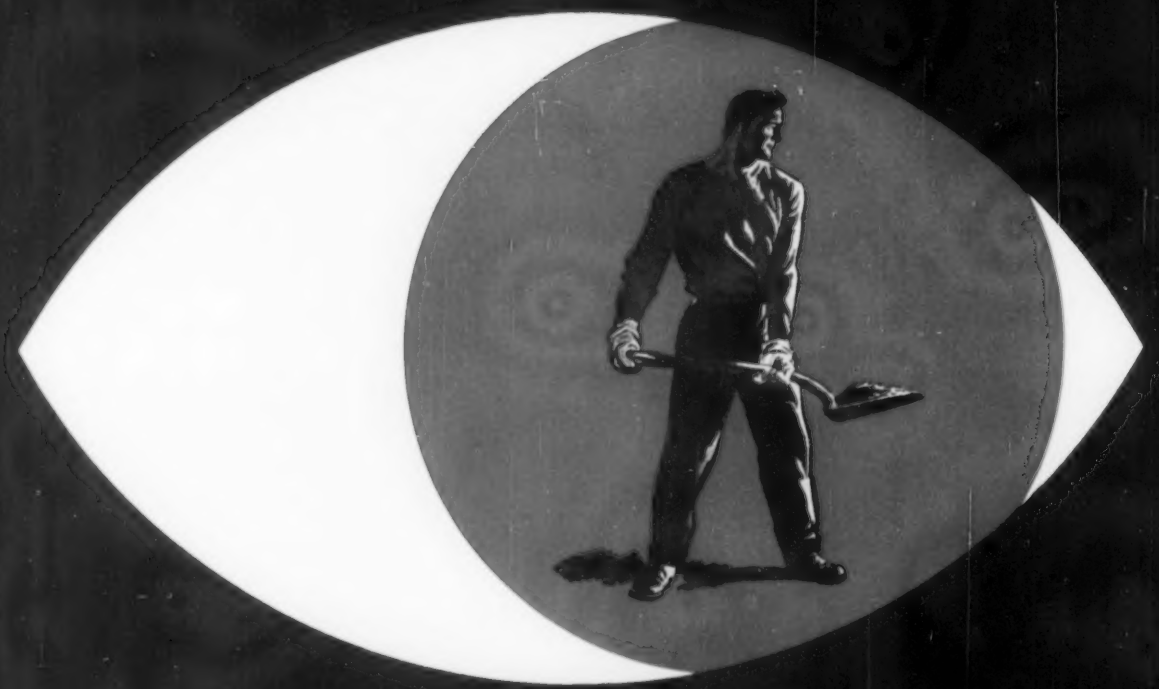


NORTON
REFRACTORIES
Engineered... Rx ...Prescribed

75 years of... Making better products...to make your products better

NORTON PRODUCTS: Abrasives • Grinding Wheels • Machine Tools • Refractories • Electro-Chemicals — BEAR-MANNING DIVISION: Coated Abrasives • Sharpening Stones • Pressure Sensitive Tapes

capacability

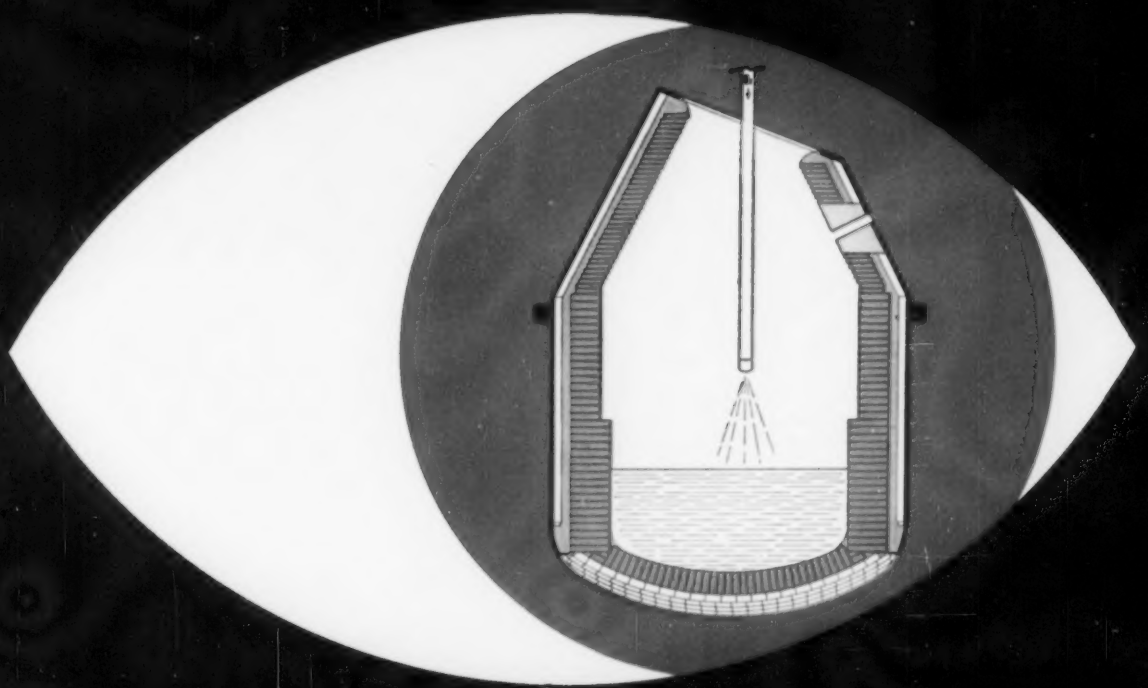


Basic reflects *Capacability* . . . the *capacity* to manufacture and deliver quality refractories — the *ability* of talented and creative people to do a better job through vision, resourcefulness and skill. With capacability, Basic continues to develop and furnish steelmakers a complete line of better hearth lining and maintenance materials — dead-burned dolomites; ramming, gunning and patching refractories; and tar-bonded linings for the new oxygen furnaces.

basic incorporated

HANNA BUILDING
CLEVELAND 15, OHIO

looking ahead to better tar-bonded oxygen furnace refractory linings



When it comes to producing better linings for oxygen steelmaking furnaces, *Capacability* is a must! And, *capacability* is Basic: in development, production, application.

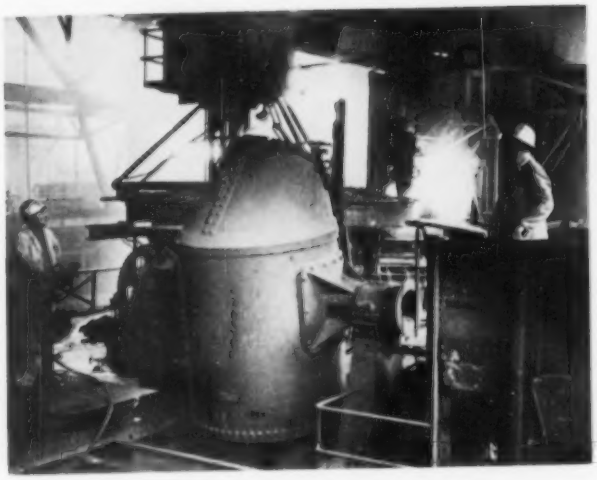
In the early 1950's, Basic—envisioning acceptance in this country of the "LD" oxygen process—studied every operating furnace in the free world. A development program was then launched to produce superior refractory linings for these furnaces. It was only natural that in 1954 the first U. S. oxygen steel producer looked to Basic for furnace refractories. We were ready. Today Basic is one of the two dominant suppliers of tar-bonded oxygen furnace linings—shipping to virtually every producer in the Western Hemisphere.

Basic's tar-bonded refractories, *Tarblok* and *Tarmix*, are manufactured to exacting specifications. Produced in a special plant adjacent to the company's Maple Grove, Ohio works, both *Tarblok* and *Tarmix* compositions are comprised primarily of dead-burned dolomite from this completely integrated facility and/or dead-burned magnesite from Basic's Gabbs, Nevada plant. These fully combined facilities enable us to precisely control physical and chemical properties of tar-bonded refractories.

In the challenging decades ahead, Basic will continue to pioneer better lining and maintenance materials for oxygen steelmaking through its experience, vision and skill—through its *Capacability*.

LD...

in the beginning



1948 . . . the first top-blown oxygen converter at Gerlafingen, Switzerland.

Where did it come from? Who developed it? And how did it all start in the first place?

by F. Weston Starratt

Not all of the facts concerning the origin of the top-blown oxygen converter are well known in America. Called the LD, or Linz-Donawitz process, the Austrian origin of the process is generally assumed, and commercial development of the process can be certainly laid to Austria, but we must go farther back to start our story.

The idea of converting iron into steel with pure oxygen is over 100 years old and was expressed in some of the Bessemer patents. But little was done with the idea until some 30 years ago when oxygen was beginning to be made available at an attractive enough cost to mean its commercial utilization in steelmaking.

The threads of the LD story can be more directly traced to a professor of metallurgy in Berlin, named Robert Durrer. For many years he preached the doctrine of the utilization of pure oxygen rather than air in metallurgical processes, and particularly for the conversion of pig iron into steel. From 1933 until the outbreak of World War II, he conducted experiments on various steelmaking techniques making use of oxygen. Brief industrial application of some of his ideas came during wartime Germany. Returning to his native Switzerland after World War II, he became associated with the largest of Switzerland's steel plants, the Gerlafingen works of the Gesellschaft der Ludw. von Roll'schen Eisenwerke A.G.

During World War II, Switzerland, starved for steel supplies, made every effort to expand production based on her meager deposits of relatively low-grade ore. Post-war Switzerland, still remembering her wartime problems, welcomed any new steelmaking ideas which could make possible the economic utilization of Swiss raw materials. Into this picture stepped Robert Durrer, and he proceeded to set up an experimental oxygen steelmaking shop at Gerlafingen.

The year was 1947, and Professor Durrer, unable to purchase needed metallurgical equipment in Europe, bought an experimental 3-ton converter in the United States. This small apparatus, which is pictured in this article, became the first top-blown oxygen converter. A description of the first experiments on this converter was given by Professor Durrer himself in the Gerlafingen plant newspaper in May 1948. A free translation from the German points out that;

". . . on the first day of spring, our 'oxygen man' Dr. Heinrich Hellbrügge carried out the initial tests and thereby for the first time in Switzerland hot metal was converted into steel by blowing with pure oxygen. . . . With this treatment of 1 ton of metal the first practical step on a thorny passage has been undertaken. The target is the production of iron in our country in a favorable enough fashion to promote transformation into a world iron production center, proportionally speaking."

Added at the bottom of this same article is news that, "On Sunday the 3rd of April 1948, several further blowing trials were successfully carried through, whereby . . . results showed that more than half of the hot-metal weight could be added in the form of cold scrap, i.e., for 1 ton of hot metal with about 1.5 pct Si and under 0.1 pct P, a full half-ton of scrap could be added, which is melted through the blast-produced heat."

The dream of utilizing the top-blowing oxygen process to put Switzerland on the map as a major steel producer did not, unfortunately, succeed. But this development, starting at the Gerlafingen works of Von Roll, did start a chain of events moving, the full impact of which is only beginning to be felt today.

To carry through our story, we must back track several years and recall the unbalanced state in which the Austrian steel industry was left in at the close of World War II. The largest potential producing unit at Linz, which had been built by the German, Herman Goering trust, had excess hot metal for its limited steelmaking capacity. Austria, desirous of rehabilitating her economy and becoming as self-sufficient as possible, was exceedingly anxious to expand steel producing facilities at Linz. But the blast-furnace hot metal was unsuitable for bessemer treatment, and the scarcity of capital precluded strong consideration of the erection of an open-hearth shop.

Looking for a way out of this situation, engineers of the United Austrian Iron & Steel Works (VOEST) at Linz began investigating oxygen refining processes, first in the open hearth. These experiments were not a complete success, and the results obtained at Gerlafingen were reason enough to believe that the top-blowing of oxygen in a converter-like vessel might be successful. Thus, Th. Suess, works manager of VOEST, took up this idea, and after various experiments involving the position of the lance in relation to the bath, the distance between the nozzle and the bath, the oxygen supply, and the cross section of the nozzle, VOEST started with a series of 2-ton converter tests which reached a successful conclusion in June 1949.

These tests were followed by pilot-plant development in 5 and 10-ton vessels at the Donawitz plant of the Osterreichisch-Alpine Montangesellschaft and a 15-ton vessel at Linz. Results, which were presented to a meeting of the Eisenhütte Osterreich in December 1951, gave clear indication that production costs could be expected to be much lower than for the open-hearth. This consideration, together with the technical results, prompted the managements of the two firms to build production plants. VOEST's LD plant went into operation in November 1952, and Alpine's plant in May 1953.

More than three years had elapsed between the first successful heat blown at Linz in June 1949 and the start-up of the first LD plant by VOEST. More than five years went by between that first successful heat and the commencement of operations at the first LD plant outside Austria—Dominion Foundries & Steel Ltd., at Hamilton, Ontario, Canada in August 1954.

Since that time developments have moved at an ever faster pace in today's revolution in steelmaking.

THE PLACE OF BASIC OXYGEN STEELMAKING

An introduction to a special issue of JOURNAL OF METALS *devoted to the revolutionary basic oxygen steelmaking processes.*

by A. B. Wilder

In the United States in 1959, more than 87 pct of the total steel output was from open-hearth furnaces. Electric furnace output was 9 pct of the total, with the basic oxygen and acid bessemer processes accounting for the remainder.

Open-hearth capacity in recent years has been increased with larger hearths and the use of oxygen rather than with the installation of new facilities. The result was an increase of 93,250 tons of annual capacity in 1959.

Basic oxygen steelmaking capacity has been increased, due to the installation of new facilities and the increased heat size of existing installations. An increase of 124,240 tons of capacity occured in 1958, resulting in a total oxygen steelmaking (LD) capacity of 4,157,000 tons annually; it is expected that this capacity will be increased by over 100 pct by 1962. For economic reasons, the trend in the US is, therefore, toward increased production of basic

A. B. WILDER is chairman of the Acid Converter and Basic Oxygen Steel Committee, and chief metallurgist, National Tube div., U. S. Steel Corp.

LD steelmaking at Jones & Laughlin's Aliquippa, Pa., plant. Photo by David Cain.

oxygen steel. High-phosphorous ores are not available for basic bessemer steel. Also, the ores for acid bessemer steelmaking are limited and, if necessary, may be used for production of basic iron. Further, the control of nitrogen in the basic oxygen process provides a product in open and semi-killed steels which has desirable properties.

It is also interesting to observe the influence of the basic oxygen process on steel production in various parts of the world, particularly where high-phosphorous ores are not available in sufficient quantities. The total world capacity of basic oxygen steel outside of the US is over 12 million tons annually. It is expected that this capacity will be doubled by 1962 with new facilities coming into operation. There will also be an additional increase in capacity, due to larger heats in existing vessels.

Basic oxygen facilities with vertical lances and stationary vessels or horizontal lances and rotating vessels are in operation, under construction or being considered in the following countries: South Africa, Australia, Austria, Belgium, Brazil, Canada, West Germany, Finland, France, India, Italy, Japan, Luxembourg, Netherlands, Norway, Philippine Islands, Portugal, Scotland, Spain, the UK, the US, and the USSR. A capacity over 1 million tons annually exists in each of the following countries: Austria, Brazil, Canada, West Germany, Japan, the UK, the US, and the USSR. Information concerning the basic oxygen facilities in China is not available; however, it is well known that China is appreciably increasing steel production facilities.

In 1959 approximately 323 million tons of steel were produced throughout the world. If all of the basic oxygen capacity had been used for producing steel, this would have accounted for approximately 5 pct of the total steel produced. Basic oxygen steel is being produced in new locations throughout the world, and the capacity of existing facilities is also being increased. This will change steel imports for these countries in the future. Many countries throughout the world desire to develop, for economic and political reasons, various basic industries, such as steel. The trend in installing basic oxygen facilities is apparently based on favorable capital expenditures and production costs, in addition to suitable quality characteristics. It is, therefore, apparent that this process has become an important steelmaking process, which depends on the availability of low-cost tonnage oxygen. Basic oxygen steelmaking will continue to increase in importance throughout the world.

The ability to melt scrap in the basic oxygen process is limited when compared with the open-hearth process. In the steel industry a balance in the use of scrap and molten iron must exist. This depends to some extent on the product mix. For example, scrap generated in a mill for the production of sheet steel would be less than in a mill producing seamless steel pipe. The ability of the open-hearth to melt large quantities of scrap has an important bearing upon the future usefulness of this process. Therefore, there will be a limitation in the growth of the basic oxygen steelmaking process for certain products and plant locations, until its scrap melting capacity is increased. Cupolas are being used for melting scrap, and such facilities are currently established in the US.

In the actual production of basic oxygen steel the most important metallurgical factors to control are uniformity of the product and a low nitrogen content in the finished steel. Uniformity of the product is, in part, related to the pouring temperature of the steel. Nitrogen content is related to the purity of the oxygen and design of the vessel. These factors have been currently established at satisfactory levels and are related to continued acceptance of the product.

A triumvirate of Basic Oxygen Steelmaking: P. Coheur (LD-AC), H. Trenkler (LD), Bo Kalling (Kaldo), shown l to r.

THE PHYSICAL CHEMISTRY OF OXYGEN STEELMAKING

A survey of the chemical and thermal aspects of basic oxygen steelmaking as compared with other processes. The equilibria relationships for the basic open-hearth process studied over a 35 year period, are equally valid for oxygen steelmaking. However, the kinetics of the process are different. It is these similarities and differences which this article defines.

by D. L. McBride

Pneumatic steelmaking processes have many attractive features, among which are low capital cost, low operating cost, simplicity of operation, and the ability to make low carbon steels at high production rates. There are, however, other factors beside production rate that influence the selection of steelmaking methods for production of quality steels at minimum cost. The advantage of speed, inherent in pneumatic steelmaking processes, is off-set to some extent by their limited ability to melt scrap, the absorption of nitrogen by the steel particularly when using an air blast, problems of air pollution and by the fact that they are not especially suitable for the manufacture of alloy steels and carbon steels containing more than 0.25 pct C. The use of commercially-pure oxygen instead of air for refining the metal has eliminated or minimized these limitations and has improved the thermal aspects of pneumatic steelmaking, but the use of commercially-pure oxygen will in no way alter the basic chemical reactions and equilibria involved in steelmaking.

The chemical reactions of greatest importance in steelmaking are those involving oxygen with iron, carbon, manganese, silicon, and phosphorus, and sulfur with lime. In their most simple form these chemical reactions and their equilibrium constants can be written as:

$$Fe + O = FeO \text{ (in slag)}$$

$$K_{Fe} = \frac{(FeO)}{[O]} \qquad [1]$$

$$C + O = Co \text{ (Gas)}$$

$$K_{C} = \frac{P_{co}}{[C]\,[O]} \qquad [2]$$

$$Mn + O = MnO \text{ (in slag)}$$

$$K_{Mn} = \frac{(MnO)}{[Mn][O]} \qquad [3]$$

$$Si + 2O = SiO_2 \text{ (in slag)}$$

$$K_{Si} = \frac{(SiO_2)}{[Si][O]^2} \qquad [4]$$

$$2P + 5O = P_2O_5 \text{ (in slag)}$$

$$K_{P} = \frac{(P_2O_5)}{[P]^2[O]^5} \qquad [5]$$

$$S + CaO = O + CaS \text{ (in slag)}$$

$$K_{S} = \frac{[O]\,(CaS)}{[S]\,(CaO)} \qquad [6]$$

Although these steelmaking reactions can be described by very simple chemical equations, the equations as written indicate further complications by the fact that two phases are involved, slag and metal. To be completely accurate, the reactions should be considered as involving three phases, gas-slag-metal, since the gas is a principal source of the oxygen required in all of the chemical reactions. Thus, it is necessary to transfer oxygen from the gas to the slag and then from the slag to the metal before the chemical reactions can occur. In a relative quiescent bath, such as in an open-hearth furnace, the gas-slag-metal transfer plays an important role. Conversely, in oxygen steelmaking with oxygen gas being injected directly into the metal, the reactants are brought together rapidly and intimately, and create extreme turbulence of the slag and metal. The direct injection of oxygen and the turbulent mixing of slag and metal increase the rate of the reactions, but this increase in reaction rates can in no manner influence the equilibrium values for the reactions. It would indeed be surprising if the equilibria relationships determined for basic open-hearth steelmaking were not equally valid for basic oxygen steelmaking, for chemical equilibrium should be affected in no manner by the shape or size of the furnace, the speed of melting or refining, nor the method by which oxygen is introduced into the furnace. However, the configuration of the furnace can influence the kinetics of steelmaking by simplifying charging procedures by improving heat transfer, by permitting faster feeding of reactants, and by tolerance for extreme turbulence of the slag and the metal.

The pioneering studies on the equilibria of the important steelmaking reactions started some 35 years ago by Herty, Körber, Oelsen, and Shenck. They have since been refined and expanded by many investigators, among which the contributions of Chipman and his colleagues at Massachusetts Institute of Technology have been highly important. As a result, we now have a reasonably complete picture of the equilibria relationships for the important steelmaking reactions and the effect of temperature on these equilibria.

At all times, in open-hearth steelmaking, oxygen is absorbed from the furnace gas by the slag to form iron oxide, which is then transferred to the metal

D. L. McBRIDE is director, metallurgical process development, applied research, U. S. Steel Corp. This paper was presented at the Acid Bessemer Converter and Basic Oxygen Committee meeting in Los Angeles, May 1960.

where it reacts with the metalloids present in the bath. This transfer from gas to slag to metal is controlled largely by the turbulence, fluidity, and composition of the slag. Whether or not iron oxide increases or decreases in an open-hearth slag depends on the speed of oxidation of the slag by the gas and the speed of oxidation of the metal by the slag, the difference in the two rates resulting in changes in the iron content of the slag. However, for oxygen steelmaking, the extreme turbulence of the slag and metal should promote rapid transfer of oxygen, and as a result, one should expect to find the iron oxide content of slags in oxygen steelmaking furnaces to be somewhat lower than in basic open-hearth furnaces, at any given carbon content of the metal. This condition indeed has been experienced broadly by operators of oxygen steelmaking furnaces. Fig. 1 shows the difference in iron oxide content of open-hearth slags and oxygen furnace slags for a number of melts containing 0.05 to 0.20 pct C. The lower iron-oxide content of slags in basic oxygen furnaces immediately suggests that phosphorus elimination may be somewhat more difficult than in basic open-hearth furnaces. However, it seems that any unfavorable situation concerning phosphorus could be controlled by arbitrarily increasing the iron-oxide content of basic oxygen slags by judicious additions of roll scale or perhaps more effectively by slack blowing of oxygen for short periods with the lance in an elevated position. Slack blowing with an elevated lance should not only increase the rate of oxygen pickup by the slag, but also should minimize turbulence and decrease the rate of transfer of oxygen from the slag to the metal.

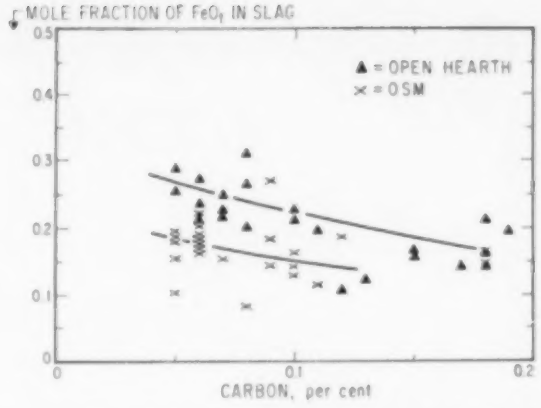


Fig. 1—Slag oxidation in basic-oxygen and open-hearth practice.

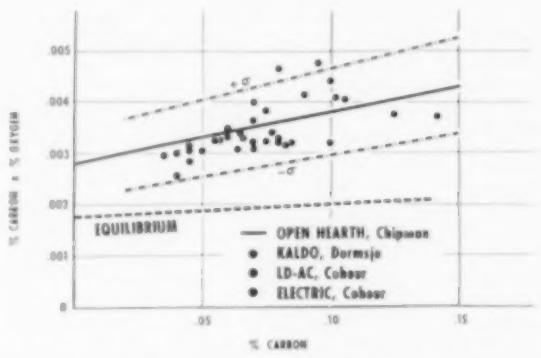


Fig. 2—Carbon-oxygen relationship in steelmaking furnaces.

Oxidation of carbon

The work of Vacher and Hamilton[1] some 30 years ago on the carbon-oxygen equilibrium in liquid iron showed that at low carbon contents the product of pct C x pct O equals 0.0025 at 1600°C. These studies on the carbon-oxygen equilibrium were extended by Marshall and Chipman[2] to higher levels of carbon and to cover the range of 1550°C to 1700°C and at pressures up to 20 atm. These later investigators showed by precise measurements that the product of pct C x pct O is not constant at any given temperature, but increases slightly with increasing carbon content. This equilibrium relationship between carbon and oxygen applies to all steelmaking processes, whether they be open-hearth, pneumatic, or electric. However, the carbon-oxygen reaction does not come to equilibrium as long as carbon is being eliminated. Furthermore, the state of oxidation of the metal is determined and controlled at all times by the amount of carbon in the bath. Data on the carbon-oxygen relationship were presented recently by Coheur[3] for LD-AC heats and electric furnace heats, and by Dormsjo[4] for Kaldo heats. Fig. 2 shows Coheur's and Dormsjo's data for carbon and oxygen, plotted with Chipman's line for the average of a large number of open-hearth heats. The scatter of Coheur's and Dormsjo's data around Chipman's line demonstrates that the carbon-oxygen relationship is not affected by the type of steelmaking furnace. Although similar data are not available from conventional LD furnaces, one must expect that any data subsequently obtained will be similarly scattered about Chipman's line for basic open-hearth heats.

Oxidation of manganese

Studies on the behavior of manganese in steelmaking under either acid or basic slags were among the earlier investigations involving slag-metal reactions. Fortunately, reaction [3] reaches a state of balance early in the progress of a heat, and maintains a condition closely approximating equilibrium. Since the oxidation of manganese is a slag-metal reaction, the equation for the reaction and the equilibrium constant can be written:

$$\underset{}{\mathrm{Mn}} + \underset{\text{(in slag)}}{\mathrm{FeO}} = \underset{\text{(in slag)}}{\mathrm{MnO}} + \underset{}{\mathrm{Fe}}$$

$$K_{Mn} = \frac{(MnO)}{(FeO)\,[\%\ Mn]}$$

where the slag terms are written as mol fractions and the manganese as wt pct.

The influence of temperature on the manganese equilibrium was determined by Chipman[5] to be

$$\log K_{Mn} = \frac{6440}{T} - 2.95,$$

which agrees with operating experience that a higher manganese residual in the metal is obtained with a higher temperature.

It is necessary, however, to consider slag constitution to obtain a complete picture of the behavior of manganese over a wide range of slag compositions.

Darken and Larsen[6] studied the behavior of manganese in a large number of open-hearth heats over a wide range of slag basicity. These investigators found that the calculated and observed manganese content of the metal were in excellent agreement for slags of a basicity ratio higher than 2.5, where basicity of the slag was measured by the mol ratio $\left(\frac{CaO - 4\,P_2O_5}{SiO_2}\right)$. Since finishing slags in basic open-hearth and basic oxygen furnaces usually have a basicity of 3 or higher, it is possible to use the manganese equilibrium relationship determined for open-hearth steelmaking to calculate the behavior of manganese in basic oxygen furnaces. Fig. 3 shows the calculated and actual manganese contents of a number of low-carbon basic oxygen heats for which the slags ranged from 1.69 to 10.40 pct MnO as a result of the furnace being charged with hot metal ranging in composition from 0.22 to 2.54 pct Mn. From Fig. 3, one can draw the conclusion that the observed behavior of manganese in basic oxygen furnaces, i.e., that the residual manganese is consistently higher than in basic open-hearth furnaces, is explainable by the fact that open-hearth furnaces lose a substantial amount of manganese from the system by the flushing of early slags, and the probability that steel tapped from basic oxygen furnaces is likely to be a bit hotter than the same grade of steel tapped from basic open-hearth furnaces. This matter of temperature may no longer apply after basic oxygen furnaces are built to tap the same size heats as are now produced by basic open-hearth furnaces.

Elimination of phosphorus

The elimination or control of phosphorus is a matter of primary concern in all steelmaking processes. Since practically no phosphorus can be eliminated in acid steelmaking furnaces, the only means for control of phosphorus in such furnaces lies in the careful selection of raw materials low in phosphorus. Although acid steelmaking processes are usually somewhat simpler than the counterpart basic processes, the fact that basic steelmaking processes can eliminate 97 to 98 pct of the phosphorus from the charge is the basis for the almost exclusive use of basic steelmaking processes throughout the world.

Basic open-hearth furnaces, particularly in the US, are usually charged with enough hot metal to allow flushing of the early slag from the furnace. With a flushing practice, open-hearth furnaces are able to produce low-phosphorous steels without undue difficulty, even when the hot metal contains as much as 0.4 to 0.5 pct P. To make basic oxygen steels with the same low phosphorus content as open-hearth steels requires the use of hot metal containing no more than 0.15 to 0.18 pct P. However, basic oxygen furnaces can produce low-phosphorous steels from intermediate- and high-phosphorous pig irons when the oxygen furnace is operated similarly to open-hearth furnace, i.e., flushed or deslagged about midway through the heat cycle. Cuscoleca and Rösner[7] quoted results from Yawata Iron & Steel Co., as shown in Fig. 4, indicating the successful use of a two-slag practice to produce low-carbon steel, averaging 0.013 pct P when using hot metal in the charge containing as much as 0.40 pct P.

Because of the industrial importance of basic open-hearth steelmaking, it was natural that most laboratory research on the behavior of phosphorus in steelmaking should be done under metallurgical conditions simulating those existing in basic-hearth furnaces. Despite the tremendous importance of phosphorus control for the manufacture of steels of acceptable quality, the complexity of the slag-metal reactions involved in eliminating phosphorus has presented formidable obstacles to research workers in their studies on this problem.

One of the greatest difficulties has been in developing a concept of slag constitution. The reported chemical analysis for slags is always in terms of the various oxides, CaO, MgO, SiO_2, Al_2O_3, P_2O_5, MnO, FeO, and others. Experimental studies have shown that these oxides do not form ideal solutions and it is necessary, therefore, to assume that certain amounts of these oxides combine as stable chemical compounds and thus are rendered inactive, for example, $2\,CaO{\cdot}SiO_2$ or $4\,CaO{\cdot}Fe_2O_3$. Such assumptions are acceptable only because they are useful for illustrating slag-metal behavior, but they have no firm scientific basis .

Open-hearth operators have long known that phosphorus elimination is favored by high basicity, high slag oxidation, and low temperature. However, the quantitative aspects of phosphorus elimination are difficult to resolve, largely because of a lack of understanding of liquid slag constitution, particularly concerning the active and inactive constituents in liquid slags and the proper method for calculating the degree of basicity of the slag.

Many different concepts of the constitution of liquid slags in basic steelmaking furnaces have been proposed by various investigators. Without discussing the various concepts of slag constitution, the results of the several research studies can be com-

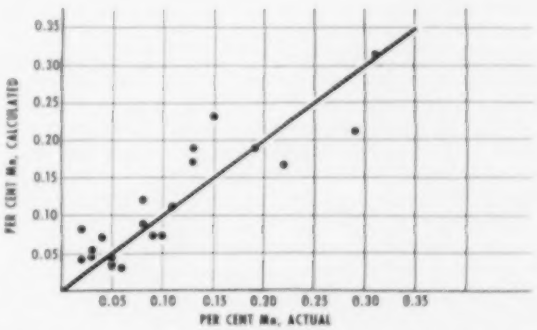


Fig. 3—Calculated vs actual manganese content of bath in LD vessel.

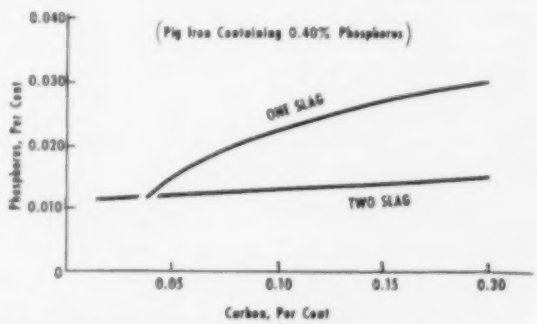


Fig. 4—Relation between carbon and phosphorus in LD vessels at Yawata plant in Japan, using one and two slags. After Cuscoleca and Rösner.

pared to show quantitatively the sensitivity of the phosphorus reaction to temperature, a matter of great concern in oxygen steelmaking. Fig. 5 shows the effect of temperature on the amount of phosphorus in the metal at a fixed condition of slag basicity and oxidation. The relationship shown by Balajiva[9] seems to correspond more nearly to observed conditions in basic steelmaking than do the curves shown for the results of the other studies. Grandpierre[11] shows that the phosphorus reaction is not sensitive to temperature and thus dephosphorization would be controlled entirely by the basicity and oxidation of the slag. In contrast, Turkdogan[5] and Winkler[10] show such strong influence of temperature on the phosphorus reaction that temperature would appear to be more important than slag basicity and oxidation.

The slag and metal analyses from a number of heats from basic open hearth furnaces and basic oxygen furnaces were used to calculate the phosphorus content of the metal from the relationships developed in the studies shown in Fig. 5. The best agreement between the calculated and the actual phosphorus content of the metal was shown by Balajiva's relationship, Fig. 6. The poor agreement between the calculated and actual phosphorus contents of the steel indicates the need for further research on the constitution of liquid slags and the effect of temperature on the phosphorus reaction.

Elimination of sulfur

The mechanism governing the elimination of sulfur is perhaps even more poorly understood than the reactions involved in the removal of phosphorus. The qualitative aspects of both phosphorus and sulfur removal include high basicity, fluid slags, and a lively bath action. However, compared with phosphorus removal, sulfur elimination in basic steelmaking is relatively inefficient. As mentioned previously, basic slags can remove as much as 98 pct of the phosphorus from the charge but only about one-third of the sulfur can be eliminated from the metal in basic steelmaking. Stated in another way, the distribution ratio of phosphorus between a highly-basic slag and the metal is at times as high as 100, whereas the distribution ratio of sulfur between the same basic slag and the metal will usually be about 4 to 6 and will seldom exceed a ratio of 8 to 10. Thus, in a basic open-hearth furnace in which the slag weight is about one-tenth that of the metal, it is not unusual to find that more pounds of sulfur are retained in the metal than are absorbed by the slag. Accordingly, the most positive control of sulfur is not to be found in drastic manipulation of slag composition and in elaborate systems for slag control, but it is accomplished only by avoiding the use of high-sulfur charge materials and high-sulfur fuels. The generally accepted mode of transport of sulfur from the metal to the slag is shown by the equations:

$$\underset{\text{in slag}}{CaO} + S = \underset{\text{in slag}}{CaS} + O \qquad K = \frac{(CaS)}{(CaO)}\frac{[O]}{[S]}$$

$$\underset{\text{in slag}}{MnO} + S = \underset{\text{in slag}}{MnS} + O \qquad K = \frac{(MnS)}{(MnO)}\frac{[O]}{[S]}$$

$$\underset{\text{in slag}}{Mgo} + S = \underset{\text{in slag}}{MgS} + O \qquad K = \frac{(MgS)}{(MgO)}\frac{[O]}{[S]}$$

These reactions show that desulfurization is favored by a high concentration of basic oxides in the slag and a low oxygen concentration in the metal. From a series of laboratory melts, Grant and Chipman[12] developed a relationship between the *excess base* in a slag and the sulfur distribution, (S)/[S], between the slag and metal in which CaO, MnO, and MgO are considered as bases and combine on a molar basis with 2 mols SiO_2, 4 mols P_2O_5, 2 mols Al_2O_3, and one mol of Fe_2O_3. The mols of bases per 100 g of slag remaining after satisfying the acid constituents are then termed the *excess base*. Fig. 7 shows the relationship determined by Grant and Chipman from laboratory melts, compared with data from a series of basic oxygen (LD) heats and for oxygen heats in which the burnt lime was injected through the oxygen lance (OLP). The data for the oxygen furnace melts show considerable scatter about the line developed from laboratory melts; however, Grant and Chipman also found considerable scatter when their calculation was applied to operating data from open-hearth heats. The numerous, unusually high distribution ratios of 12 to 14, shown in Fig. 7, compared with open-hearth experience where the (S)/[S] ratio seldom exceeds 8 to 10, is perhaps a reflection of the extreme turbulence and good mixing of slag and metal and the ease with which highly-basic slags can be produced in basic oxygen furnaces. It is noteworthy that injection of lime through the

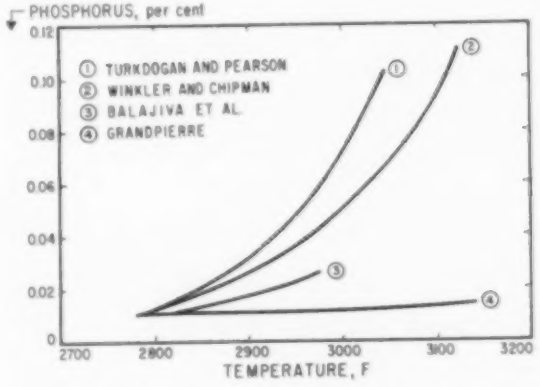


Fig. 5—Effect of temperature on residual phosphorus.

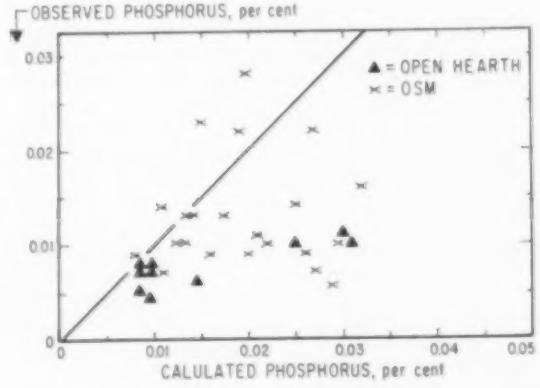


Fig. 6—Observed vs predicted phosphorus.

lance (OLP) did not appear to improve desulfurization over that obtained with lime introduced through a charging chute. However, a statistical study involving a large number of heats might show a slight improvement in desulfurization when using the practice of lime injection through the oxygen lance.

Effect of oxygen purity on N content

The significant pick-up of nitrogen by the steel from the air blast has handicapped the thomas and bessemer steelmaking methods in producing steels for deep drawing applications. According to Siverts law, the solubility of nitrogen in liquid steel is proportional to the square root of the partial pressure of nitrogen which, at 1600°C and under a pressure of 1 atm of nitrogen, corresponds to a nitrogen content of the steel equal to 0.040 pct. Accordingly, European operators of thomas vessels have been forced to use an oxygen-enriched blast or a steam-oxygen blast to decrease the partial pressure of nitrogen so as to avoid excessive pick-up in their steel near the end of the blowing period. The solubility of nitrogen in steel also increases with temperature, and therefore it is not surprising to find that designers and operators of basic oxygen furnaces have believed it necessary to use almost pure oxygen to avoid the pick-up of nitrogen by the steel in the unusually high-temperature reaction zone immediately under the oxygen lance.

A study of the relationship between the nitrogen content of the blast and the nitrogen content of the steel produced in a basic oxygen furnace shows that the nitrogen content of the steel increases with an increase in the nitrogen content of the blast. Fig. 8 shows that a blast containing 98 pct O_2 and 2 pct N_2 will produce steels containing 0.004 to 0.005 pct N, or approximately the same nitrogen content as basic open-hearth steels. However, if water is injected into the oxygen lance to act as a coolant by suppressing the high temperature of the reaction zone, the nitrogen content of the blast can be as high as 14 pct before the steel contains as much as 0.004 to 0.005 pct N. From a technical viewpoint, water injection into the oxygen blast can be a very effective means for controlling the nitrogen content of the metal; however, from an economic viewpoint the use of water may be undesirable because its powerful cooling effect significantly decreases the amount of scrap that can be melted in oxygen steelmaking furnaces.

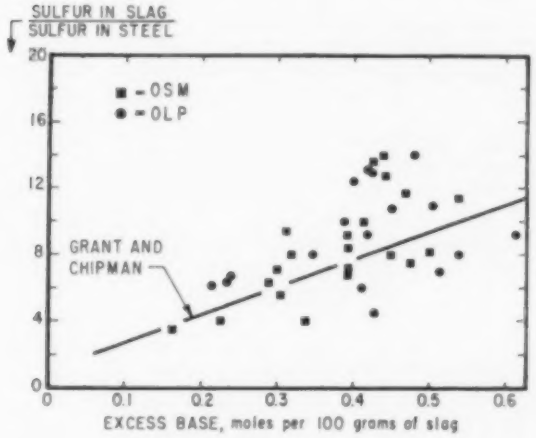


Fig. 7—Slag basicity vs sulfur distribution.

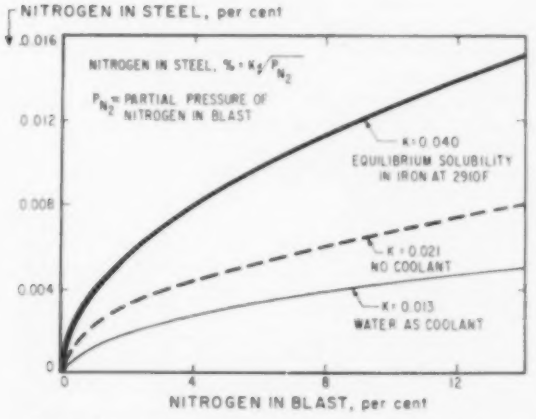


Fig. 8—Oxygen purity vs nitrogen content of acid LD steel.

Thermal aspects

The importance of temperature control in open-hearth and electric furnace steelmaking and its effect on steel quality, pouring practice, ingot yield, and furnace life is well known to operators and metallurgists. In these steelmaking furnaces, adjustments can be made, if necessary, during the progress of the heat to alter the composition of the metal or the slag, and the temperature of the bath can be increased or decreased as desired. In oxygen steelmaking, temperature control is no less important than in the older processes, but the high speed of the operation, the impracticability of sampling the bath for chemical composition or temperature without cessation of blowing, and the great variety of sources of heat and heat losses introduces a complexity into the problem of temperature control for oxygen steelmaking furnaces that is not encountered in open-hearth and electric furnace steelmaking.

Altogether, there are at least 14 important factors that either generate or absorb heat, for which the combined heat effects must be considered if precise control of temperature is to be achieved in oxygen steelmaking. Fortunately, most of the basic information concerning heat content at high temperature and heats of reaction for the various materials used in steelmaking are reasonably well established. Using the basic thermal constants, remarkably good heat balances can be calculated for the oxygen steelmaking process. The availability of high-speed analytical techniques and computers for solving the many equations involved in the thermal relationships should lead to temperature control of oxygen steelmaking and result in a minimum time loss for backcharging of scrap to cool excessively hot heats or for recarburizing and reblowing excessively cold heats. The first steps toward computer control of the temperature in oxygen steelmaking have already been undertaken at Jones & Laughlin Steel Corp. with very encouraging results.[18] The use of a computer for control of tapping temperature requires a knowledge of the cooling effect of the various materials that must be heated to the desired steelmaking temperature, as well as a knowledge of the temperature and composition of the hot metal used in the

charge and the heat generated by the oxidation of the various metalloids.

Use of coolants

The two aspects of oxygen steelmaking that have stimulated the spectacular growth of this method, compared with the older pneumatic processess, are its ability to produce low-nitrogen steels and its use of substantial amounts of scrap. In the older processes, bessemer and thomas steelmaking, a tremendous amount of heat is carried out of the vessels by the nitrogen in the effluent gas. The amount of heat generated, and the amount of oxygen required to refine a ton of pig iron is the same regardless of whether the oxygen is introduced by bottom-blowing or by top-blowing, or whether the refining is done in acid-lined or basic-lined furnaces.

The composition of the iron and the composition of the effluent gas determine the amount of heat generated and the amount of oxygen required to refine a ton of pig iron. Except for the Kaldo and Oberhausen rotor furnaces, the effluent gas from pneumatic steelmaking furnaces is predominately carbon monoxide plus whatever nitrogen was introduced with the blast. Any portion of this carbon monoxide that is burned within the furnace to carbon dioxide will require additional oxygen and will generate additional heat. If all of the heat generated in the refining of 1 ton of pig iron could be recovered in the steel, this heat would raise the temperature of the steel by 2300°F and 3050°F when the carbon was burned respectively to CO and CO_2. In the older pneumatic processes where air is the primary source of oxygen, most of the heat released by the oxidation of metalloids is carried out of the vessels by the nitrogen from the blast air. However, in oxygen steelmaking there is practically no nitrogen present to dissipate the heat of the reactions and, therefore, a coolant of some type must be added to prevent excessive overheating of the refined pig iron.

Any material that is compatible with the steelmaking process can be used as a coolant, and the choice of the coolant will be governed by local conditions in each melt shop. The most practical coolants for basic oxygen steelmaking are scrap, burnt lime, limestone, roll scale, iron ore or agglomerates, and water. The effectiveness of each of these materials as coolants is determined by their specific heats, except for limestone and water which in addition undergo chemical reactions that absorb heat. The heat quantities involved in the reactions of water and limestone, and the heat content data by Kelley[14] and the data from Elliot and Gleiser[15] can be used to calculate the potential cooling effect of each material by determining the amount of heat required to raise its temperature to 2900°F, the assumed steelmaking temperature. Table I gives the amount of heat absorbed, in Btu per lb for each of the principal coolants that can be used in basic oxygen steelmaking.

The cooling effect shown for oxygen is the amount of heat required to heat oxygen gas from 77° to 2875°F, the assumed temperature of the furnace. Chemical reactions between oxygen and the metal bath will, of course, generate heat and these thermal relationships will be discussed later. Other than for oxygen, Table I shows that scrap is substantially poorer and water is substantially better as coolants than are the other materials used in steelmaking. It is fortunate that scrap is such a relatively poor coolant, because it permits the melting of a large proportion of scrap in the oxygen steelmaking furnace. However, barely enough heat is generated in oxygen steelmaking furnaces to consume the revert scrap in many plants and supplementary sources of heat will be required to consume the scrap available from customers and dealers. Table I also indicates that temperature control could be achieved, even if no scrap were used in the charge. If desirable in special circumstances, it should be possible to develop a practice using suitable combinations of roll scale or iron ore, lime or limestone, and steam or water as coolants instead of scrap.

Sources of heat

Although the published data are meager on heat balances and material balances for oxygen steelmaking operations, the information given by Loughrey[16] for the operation at Aliquippa is useful for comparison with calculations based on thermal data for the high-temperature chemical reactions involved in steelmaking. For simplicity, it may be assumed that the scrap used at Aliquippa has the same composition as the final steel; therefore, all heat generated in the process results from the oxidation of metalloids in the pig iron. Thus, from published data[14,15] on the heat content of steelmaking materials at high temperature (2875°F) and the heat given off by oxidation of the various metalloids, it is possible to calculate the amount of scrap that can be melted for each ton of pig iron processed.

Loughrey's data for the Aliquippa operation gives most of the information required for calculating a heat balance for oxygen steelmaking. In addition to the data given, it is necessary to make the following assumptions, all of which are believed to be fairly representative of the operation at Aliquippa. Although not strictly valid, it was also assumed that the scrap used in the charge had exactly the same composition as the metal in the furnace at the end of blowing.

Assumptions

	Pct				
	C	Mn	P	Si	Temp, °F
Avg hot metal	4.30	0.50	0.112	1.30	2600
Avg at end of blow	0.10	0.05	0.012	0.00	2875
Slag vol	300 lb per ton of steel				
Slag Comp	$CaO/SiO_2 = 3.2$, 15 pct FeO, 5 pct FeO				
C oxidation	90 pct to CO, 10 pct to CO_2				

Using the above assumptions and the material balance given by Loughrey, the amount of heat generated by oxidation of metalloids and the amount of heat absorbed by the coolants, other than scrap, can be calculated. Thus, the difference between the amount of heat generated and the amount of heat absorbed indicates the amount of heat available for melting scrap, which can be divided by the heat content of 1 lb of molten iron at 2875°F to give the pounds of scrap that can be melted within the validity of the conditions assumed for the Aliquippa operation. Table II gives the results of the heat balance calculations and shows that Aliquippa should be melting 917 lb of scrap per ton of hot metal compared with 930 lb reported by Loughrey.

The excellent agreement between the calculated weight of scrap and the actual weight of scrap used at Aliquippa is not exactly fortuitous but really is the result obtained, if the assumed conditions are valid. For example, if the actual temperature of the hot metal at Aliquippa averages 100°F hotter or

colder than the assumed temperature of 2600°F, then the heat balance would have shown either 60 lb additional or 60 lb less scrap than the calculated amount, 917 lb, given in Table II. Also, it is not strictly correct to assume that the analysis of the scrap used in the charge is exactly the same as that of the blown metal. If the actual analysis of the scrap is 0.15 pct C, 0.35 pct Mn, and 0.05 pct Si, the oxidation of these metalloids to the assumed level of the blown metal would make sufficient heat available to melt 23 lb of additional scrap, or roughly, 2 to 2.5 pct of the initial weight of the scrap charge.

Earlier calculations by McMulkin[17] and Philbrook[18] on the thermal relationships in oxygen steelmaking furnaces indicate that only 670 lb of scrap per ton of hot metal could be consumed when the hot metal contains 1.30 pct Si, such as the iron used at Aliquippa. How then is it possible for Aliquippa to consume 930 lb of scrap or roughly 40 pct more than reported by McMulkin and calculated by Philbrook?

It appears that insufficient consideration has been given to the important amount of heat that can be lost through the nose of the furnace by radiation from the hot walls or bath surface at all times, except when the effluent carbon monoxide is being burned to carbon dioxide at the nose of the furnace. When blowing is in progress, the furnace charge may receive a small amount of heat by back radiation from gases burning at the nose of the furnace, but at all other times the radiation loss is estimated to be between 3000 and 4000 Btu per min per sq ft of nose opening. From Table I, this amount of heat is sufficient to melt 5 to 6.5 lb of scrap for each square foot of nose opening. Therefore, a delay of 10 min, or the equivalent for a slowly paced operation of a furnace with a 30 sq ft nose opening, would consume 1500 to 2000 lb less scrap per charge than a rapidly paced operation, such as practiced at Aliquippa.

Thus, the elementary aspects of computer control of tapping temperature have been fairly well defined. A knowledge of the composition of the hot metal permits accurate calculation of the heat that will be generated by oxidation of the metalloids in the iron, and the amount of heat absorbed by heating the required oxygen and burnt lime to the desired tapping temperature. The excess heat then becomes available for melting scrap. Further experience will lead to more elaborate systems to include the thermal aspects of scrap composition, furnace delays, additions of miscellaneous materials such as fluorspar, iron ore, and ferroalloys, and the possible use of steam or water in small amounts for vernier control of temperature. Such a system appears to be not only feasible but also highly desirable, since it would increase the productivity of the furnace, decrease the cost of operation, and improve quality control.

Table I. Cooling Effect of Materials Used in Steelmaking (To heat to 2875°F)

Material	Btu per lb
Scrap	592
Oxygen	722
Fluorspar	1000
Burnt Lime	1189
Ore, Roll Scale	1280
Steam (400°F)	1415
Limestone	1520
Water	2537

Table II. Heat Balance for Oxygen Steelmaking

Sources of Heat	Lb per ton HM		Heat Generated, Btu per lb of Metalloid	Heat Generated, Btu per ton of Hot Metal
	Metalloid	Oxygen		
C to CO	75.6	100.8	4230	319,500
C to CO_2	8.4	22.4	14100	118,500
Mn to MnO	9.0	2.6	3200	28,800
P to 4 CaO·P_2O_5	2.0	2.6	15700	31,400
Si to 2 CaO·SiO_2	26.0	29.7	16250	422,500
Fe to 15 pct FeO in slag	34.5	10.4	1870	64,500
Fe to 5 pct Fe_2O_3 in slag	10.5	4.5	3190	43,500
Total	166.0	173.0		1,028,700

Coolants	Actual lb per Ton HM	Cooling Effect Btu per lb to 2875°F	Heat Absorbed Btu per Ton HM
Burnt Lime	178	1189	211,800
Roll Scale	36	1280	46,000
Fluorspar	12	1000	12,000
Ferroalloys	16	500	8,000
Oxygen	163.5	722	118,000
Refined Metal	1834	49	90,000
Total			485,900
Net Heat Available for Melting Scrap			542,800

542,800 Btu per Ton HM / 592 Btu per lb scrap to 2875°F = 917 lb scrap per ton hot metal (calculated)

930 lb scrap per ton hot metal (actual)

13 lb scrap per ton hot metal (unexplained)

Conclusions

The spectacular growth in oxygen steelmaking capacity throughout the world since 1952 when the first commercial operations were started in Austria is evidence that oxygen steelmaking is firmly based on sound metallurgical practices. It is to be expected that further research and experience with the operation of oxygen steelmaking furnaces will broaden the scope of the method, and minimize some of its present limitations concerning scrap melting, temperature control, phosphorus elimination, lining life of the furnaces, and the variety of steel grades that can be produced with ease.

References

[1] H. C. Vacher and E. H. Hamilton: The Carbon-Oxygen Equilibrium in Liquid Iron, *AIME Trans.*, 1931, vol. 95, p. 214.

[2] S. Marshall and J. Chipman: The Carbon-Oxygen Equilibrium in Liquid Iron, *ASM Trans.*, 1942, vol. 30, p. 695.

[3] P. Coheur: On the Pneumatic Process of Converting High-Phosphorus Iron, AIME Annual Meeting, Preprint, February, 1960.

[4] T. Olaf Dormsjo: The Kaldo Oxygen Steelmaking Process—Its Metallurgy and Economics, *Iron and Steel Engineer*, April, 1959, p. 67.

[5] J. Chipman, J. B. Gero, and T. B. Winkler: The Manganese Equilibrium Under Simple Oxide Slags, *AIME Trans.*, 1950, vol. 188, p. 341.

[6] L. S. Darken and B. M. Larson: Distribution of Manganese and of Sulfur Between Slag and Metal in the Open Hearth Furnace, *AIME Trans.*, 1942, vol. 150, p. 87.

[7] O. Cuscoleca and K. Rösner: The Development and Present State of the LD Process, *J. Iron and Steel Inst.*, June, 1959, p. 147.

[8] K. Balajiva and P. Vajragupta: The Effect of Temperature on the Phosphorus Reaction in the Basic Steelmaking Process, *J. Iron and Steel Inst.*, 1947, vol. 155, p. 563.

[9] E. T. Turkdogan and J. Pearson: Reaction Equilibria Between Metal and Slag in Acid and Basic Open Hearth Steelmaking, *J. Iron and Steel Inst.*, 1954, vol. 176, p. 59.

[10] T. B. Winkler and John Chipman: An Equilibrium Study of the Distribution of Phosphorus Between Liquid Iron and Basic Slags, *AIME Trans.*, 1946, vol. 167, p. 111.

[11] F. Grandpierre: S. M. Thesis, M.I.T. 1958. To be published.

[12] N. J. Grant and J. Chipman: Sulfur Equilibria Between Liquid Iron and Slags, *AIME Trans.*, 1946, vol. 167, p. 134.

[13] W. J. Slatosky: End-Point Temperature Control of the Basic Oxygen Furnace, JOURNAL OF METALS, Mar., 1960, vol 12, p. 226.

[14] K. K. Kelley: U. S. Bureau of Mines, Bulletin No. 476, Contributions to the Data on Theoretical Metallurgy.

[15] Elliott and Gleiser: Thermochemistry for Steelmaking, Addison-Wesley, vol. I, 1959.

[16] D. R. Loughrey: L-D Operations at Aliquippa, JOURNAL OF METALS, Apr., 1959.

[17] F. J. McMulkin: *AIME* Open Hearth Proceedings, 1955, vol. 38, p. 241.

[18] W. V. Philbrook: Thermochemistry of Oxygen Steel, JOURNAL OF METALS, July, 1958, vol. 10, p. 477.

NEW DEVELOPMENTS IN LD STEELMAKING

A number of recent developments have widened the area of application of the LD, basic oxygen steelmaking process. These include ore cooling, production of high-carbon and low-alloy steels, and the utilization of high-phosphorous hot metal. This article describes how these techniques have been used in 12 LD steel plants.

by Herbert A. Trenkler

During the past two or three years new developments have helped make the LD, basic oxygen steelmaking process applicable to a wider range of conditions. Most interesting of these are the utilization of high-phosphorous pig iron, the adaptation of the process to available raw materials, and the production of high-carbon and low-alloyed steels. Investigations of the metallurgy of the process point to further applications.

Phosphorous hot metal

Previously, a hot metal having a phosphorus content of 0.5 pct was considered to be the upper limit for the application of the LD process[1]. In practice, however, the majority of plants made use of hot metal with considerably lower phosphorus contents.

The Japanese steel plants were the first to use pig iron containing 0.4 to 0.5 pct P. They succeeded in proving, on an industrial scale, that it is possible to produce low-phosphorous steel from such pig iron. In a one-slag process, they modified top-blowing conditions, calling the technique *soft* blowing. As shown in Fig. 1, the result at Yawata Iron & Steel Co. was a maximum phosphorus content of 0.03 for a 0.1 pct C steel.[2] When using two slags, a maximum phosphorus content of 0.020 pct was obtained, and this two-slag technique is the typical treatment pattern for high-phosphorous hot metal.

In 1956 and 1957, the United Austrian Iron and Steel Works (VOEST) carried out tests in its steelmaking shops involving the use of pig iron containing between 0.5 and 1.5 pct P.[3] On that occasion the following conditions were recognized as being most favorable for carrying out a heat: the final slag of the previous heat should be used, and the lime should be dissolved rapidly by additional fluxes and ore. When the metal bath reaches a carbon content between 1.5 and 2.0 pct, the phosphorus content is under 0.3 pct. At this juncture, blowing is interrupted; the slag, which is relatively high in phosphorus, is removed; and after fresh lime and fluxes have been added, the blowing is continued until the desired final point is reached. Then the steel is tapped, and the slag, which is now relatively low in phosphorus, is used for the next heat. This second slag is used again, both for promoting the early formation of slag in the next heat, and for decreasing the loss of iron.

A large number of tests have been carried out involving hot metal containing more than 1.5 pct P, in other words almost thomas iron. The method used by the French firm, Société des Aciéries de Pompey and the LD-AC process used by the Luxembourg plant of ARBED at Dudelange are two processes which have led to success on an industrial level; they are discussed separately in this issue.

Adaptation to other iron

Until recently, there were still individual border cases in which the LD process was out of the question, for instance iron of a particularly low carbon content or a particularly high silicon content. Recently VOEST carried out tests in its 5-ton pilot plant in order to create conditions that would permit the blowing of practically any type of pig iron. This work is still being continued. The results obtained thus far are satisfactory, and details are expected to be published shortly. However, it can be said now that this research work has suceeded in producing steel in a two-slag technique from a pig iron of the following composition: 2.3 pct C, 0.3 pct Mn, 4.5 pct Si, 1.4 pct P, and 0.15 pct S. The steel thus produced was well suited for the production of ship plate as well as for killed and rimming deep-drawing grades.

Ore for cooling

At first, the majority of LD steel plants used scrap for cooling purposes, although tests proved that it was possible to use ore for that purpose. The Bochumer Verein plant in Germany was the first one to use the ore cooling method on an industrial scale.[4] The selection of this technique was based on a need to produce steel of low residual content. The plant's mill scrap was needed for melting in electric and open-hearth furnaces, and purchased scrap was considered to be of inferior quality. It was, therefore, decided to make use of ore for cooling LD heats, and Swedish ore pellets were selected.

Ore pellets are added at the beginning of the heat, usually all at one time, and rarely in increments. Experience showed that 1 ton of ore could replace 3.5 tons of scrap.

The first half of the required lime is charged at the beginning of the blow, and the second half after about 3 min. If necessary, smaller amounts of lime or limestone are added later. In order to obtain low phosphorus values in *caught* heats with a higher carbon content, it is better to add burnt lime. For the purpose of speeding up the formation of slag and thus promoting dephosphorization, fluorspar is added to such heats. In the case of low-carbon heats it is not necessary to add any fluxes. In all cases, blowing was not impaired by slopping.

HERBERT A. TRENKLER is professor of ferrous metallurgy at the Montanistische Hochschule (College of Mining), Leoben, Austria. This paper was presented at the 1960 AIME Annual Meeting.

In order to investigate the ore cooling technique metallurgically and compare it with scrap cooling, refining curves were plotted for the iron bath and the slag. Samples were taken from the tilted crucible with the oxygen supply having been switched off. For the same hot metal charge, several heats were represented in one curve.

In Figs. 2 and 3 for low-carbon tube steel, it can be seen that, in the case of ore cooling, silicon, manganese, and phosphorus pass more rapidly into the slag during the first minutes of blowing. The phosphorus and manganese humps of the curves are greater in this case, because of the increased supply of oxygen, originating from the ore at the beginning of the heat. The FeO content of the slag reaches its maximum at the end of the burning of manganese and silicon and prior to the begininng of the strong carbon drop. There is one FeO hump in the curve, but it disappears after 8 min. of blowing, and from there on the refining curves of ore-cooled and scrap-cooled heats are practically the same. It is, therefore, possible to say that the influence of the ore on the refining process comes to an end after 8 min.

In view of this fact, it should be expected that there would be no difference in the quality of steels produced by either of the two methods. This has been proved to be absolutely correct. Using ore as a cooling agent, Bochumer Verein has successfully produced soft, medium-hard, and hard grades of steel: for example, deep-drawing steel, tube steel, case-hardening steel, heat-treatable steel, unalloyed and low-alloyed structural steels, tool steels, and antifriction bearing steel.[4]

All hopes pinned to the ore-cooling of LD heats were completely fulfilled. In addition, the following advantages were achieved:

1) the tap-to-tap time is shorter because the addition of ore through chutes requires less time than charging scrap in the normal manner;

2) about 10 pct of the required oxygen is saved in the case of pig iron of the following analysis: 4.3 pct C, 0.5 to 1.0 pct Si, 1.0 to 1.8 pct Mn, and 0.10 to 0.13 pct P; and

3) in the event of high scrap process, production costs will be lower.

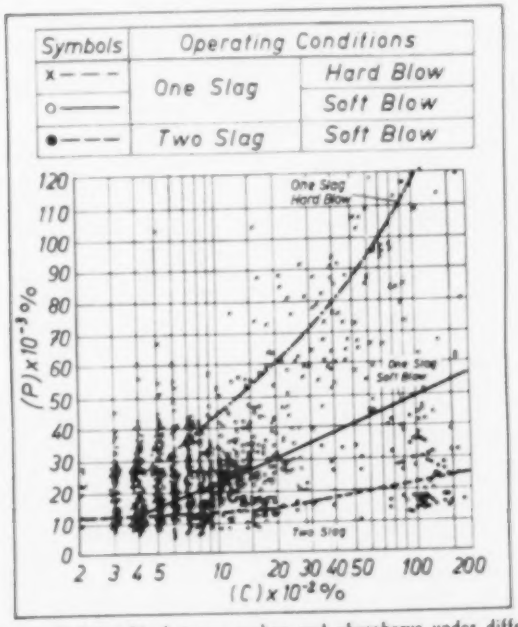


Fig. 1—Relationship between carbon and phosphorus under different melting conditions at Yawata steelworks in Japan. After S. Maehara, S. Morita, and Y. Hirose.

The pioneer work performed by Bochumer Verein brought about consideration of the case where high prices or short supplies make scrap cooling of LD heats absolutely impossible. If, however, no rich ores are available, a high proportion of gangue will somewhat restrict the use of ore. In this connection, a statement made by E. Plöckinger[10] on the occasion of the Austrian metallurgists' meeting in 1959 is quite interesting. He said that it was possible to use Renn pellets obtained in the Krupp-Renn process for cooling an LD heat in a small, 3-ton crucible. However, these pellets had been partly desulfurized, and had a sulfur content of only 0.35 pct.

In practice, cases may occur where one is interested in increasing considerably the amount of scrap charged. Recently, VOEST, in collaboration with Kaiser Engineers, carried out favorable tests in this area. Fuel was supplied to the crucible, and due to the increased chemical heat, an additional 15 pct scrap could be charged. The quality of the steel thus produced was not inferior to normal LD heats.

High-carbon and alloyed steels

In the production of high-carbon and alloy LD steels, the Österreichisch-Alpine Montangesellschaft in Austria[6, 7], and Bochumer Verein[4, 5] and Gusstahlwerk Witten[9] in Germany have been particularly active. The aim was to obtain a higher carbon steel, not by recarburizing a soft steel, but rather by catching the heat at the desired carbon content. In this manner a steel with a lower oxygen content is obtained; consequently during the subsequent killing a smalier amount of deoxidation products will arise. The fact that the consumption of oxygen is smaller, that less iron passes into the slag, and that the tap-to-tap time is shorter, are additional advantages of this method. A prerequisite for this technique is an early dephosphorization, so that at the time when the heat is caught, the phosphorus content is sufficiently low. The established methods of speeding up the slag formation can be used. If this does not help, then two slags are used. This is frequently the case when alloy steels with an especially low phosphorus content are to be produced.

In order to achieve precision in the composition of the steel produced, it is necessary to know exactly the composition of the pig iron, the weight of the hot metal charged, and the amount of oxygen consumed. Good measuring instruments are indispensible for this purpose. After a quick analysis, carbon adjustment can, if necesary, be made by an afterblow or the addition of solid carburizing agents.

Special attention must be paid to the manganese content. At a carbon content of 0.5 to 1.0 pct the maximum manganese content is reached (see Figs. 2 and 3). The formation of this so-called manganese hump depends on the temperature of the heat and the FeO content and basicity of the slag; thus, it is not always equally high. For this reason, the manganese content also has to be checked by quick analysis. When steels requiring a high manganese content are produced, attempts are made to utilize the high manganese content of the bath. If, however, a low manganese content is prescribed, as in the case of a number of wire grades and tool steels, then it is necessary to change the slag in order to remove the

Table I. Production of Rope-Wire Steel

	C, Pct	Mn, Pct	Si, Pct	P, Pct	S, Pct
Desired analysis	0.65-0.72	0.45-0.55	0.2-0.3	max 0.025	max 0.025
Actual analysis	0.68	0.50	0.28	0.016	0.016

Charging: 6 min
hot metal 34,100 kg 4 pct lime
scrap 1900 kg 2:1 pct quartz
millscale 300 kg 0.3 pct fluorspar
hot metal analysis: 4.12 pct C, 2.20 pct Mn, 0.16 pct Si

Blowing: 8 min
Analysis at end of 1st phase: bath: 2.55 pct C, 0.64 pct Mn
slag: 38.52 pct CaO, 2.73 pct MgO, 10.47 pct SiO_2, 7.7 pct Fe, 19.43 pct Mn

Sample taking and slagging off: 6 min
Additions to 2nd phase: 3.2 pct lime, 0.8 pct quartz, 0.3 pct flourspar

Blowing: 10 min
Analysis at end of 2nd phase: bath: 0.54 pct C, 0.39 pct Mn
slag: 46.20 pct CaO, 3.08 pct MgO, 11.32 pct SiO_2 9.80 pct Fe, 10.37 pct Mn

Sample taking, measuring temperature, slagging off: 7 min
tapping 2 min, adding FeSi, Al, and C for correcting purposes

Total time: 39 min

manganese. It is best to do such deslagging at the time when the manganese content in the steel bath is at its lowest, i.e. prior to the formation of the manganese hump. This deslagging takes 5 to 7 min in the case of a 30-ton crucible. Cuscoleca and Rösner[7] have published Table I covering such a typical heat.

In the same manner, case-hardening and heat treatable steels, low-alloy tool steels, ball-bearing steels, and steels for the electric industry are produced at Donawitz, Austria. The production of chrome ball-bearing steel, described in some detail on p. 678 of the October 1958 issue of JOURNAL OF METALS, is a typical example.

All of the additional procedures for higher carbon and alloyed steels take time, of course, and make the tap-to-tap time a little longer. The following survey shows the conditions prevailing in the Donawitz plant:

	Processing Time, min
Low-carbon rimming steel	32
Low carbon killed steel	34
High-carbon steel recarburized with liquid pig iron	37
High-carbon steel recarburized in the ladle	33
High-carbon steel caught	31
High-carbon steel caught after intermediate slagging off	39
High-carbon alloyed steel	44

Double slagging at Witten

At the Witten plant in Germany a new method involving two slags has been developed. The first slag which is highly basic and rich in FeO acts as a dephosphorization slag, while the second slag which contains much less FeO and is less basic does not perform any particular metallurgical task. The idea of this method is, first of all, to bring about a reliable and strong dephosphorization when the carbon content is still high, as is required in the production of alloy steels. The second is to keep melting losses of the alloying elements in alloy scrap and ferroalloys as low as possible.

In the first part of the heat, sized lime in the form of small lumps and a large amount of fluxes are used for the formation of the first slag. Blowing is done so as to obtain a rich FeO slag. After 10 min of blowing (total blowing time is 30 min) the slag contains 20 to 30 pct FeO and has a $CaO:SiO_2$ ratio of 3.5. The carbon content of the bath is high . . . between 3.2 and 3.4 pct. But the temperature of the bath has not yet increased, because the reaction heat has been used mainly for the formation of the slag. While the slag is running off, its FeO content is decreased by about 50 pct due to the strong reaction with the carbon of the bath. If the phosphorus content of the melt is 0.12 pct by the end of the first phase, a dephosphorization to under 0.02 pct P can be expected. The finished steel will then contain between 0.01 and 0.015 pct P.

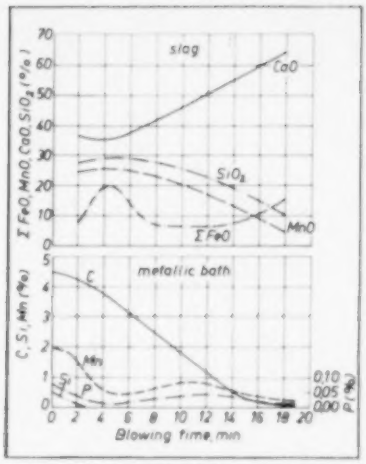
Prior to the beginning of the second phase of blowing, ferromanganese and ferrosilicon are added as chemical heat carriers. The amount added is determined by the grade of the steel to be produced, the carbon content at which the heat must be caught, and the amount of alloy scrap and ferroalloys to be added. The volume of the second slag is kept small . . . about 3 pct . . . and its $CaO:SiO_2$ ratio is between 1.6 and 2.5. Due to the rapid increase in the bath temperature, only the carbon is oxidized, while the alloying metals remain unoxidized. For this reason, chromium yield in the case of steels containing 0.1 pct C will be between 75 and 80 pct. Bath temperatures exceeding 1700°C are important for the yield of chromium, as well as for the production of steels comparable to high-grade electric furnace steels.

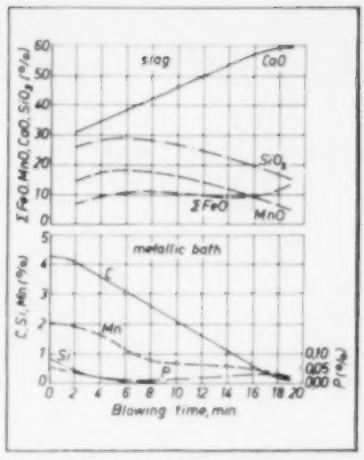
Investigations have shown that, within a carbon range of 0.4 to 1.5, the oxygen content of the steel at the end of blowing is lower than the oxygen content of a well-boiled open-hearth steel. Only in the case of a carbon content below 0.3 pct was the oxygen content slightly higher than the oxygen content of a corresponding open-hearth steel.

Inasmuch as the small amount of the second slag possesses only a low phosphorus concentration, a deoxidation with FeSi can be carried out in the crucible without danger of rephosphorization; thus, in the ensuing alloying there will be only negligible melting losses. Deoxidation also decreases temperature losses, for which reason the holding time for melting the ferroalloys can be extended up to 40 min.

Thus, Gussstahlwerk Witten has succeeded in producing in the LD vessel many grades of steel, which have heretofore been produced only in the electric furnace. It is true, however, that the special techniques employed by this firm take considerable time and that the life of the crucible is somewhat decreased, since about 30 kg of dolomite is consumed per ton of steel produced.

As far as case-hardening steels are concerned, Cr-Mn, Cr-Mo, Cr-Ni, and Ni steels are produced. Their properties correspond to those of electric furnace steels, except that their susceptibility to cementation, especially in the case of gas cementation, is a little higher. Nitriding steels containing more than 1 pct Al and alloyed with Cr and Cr-Ni proved to be equal to the best electric furnace steels. Their uniformity was particularly noteworthy. Both the unalloyed and the alloyed tool steels distinguished themselves by their low susceptibility to weak spots within a very wide range of hardness. Cr, Cr-Mn, and Cr-Si steels, containing up to 1.5





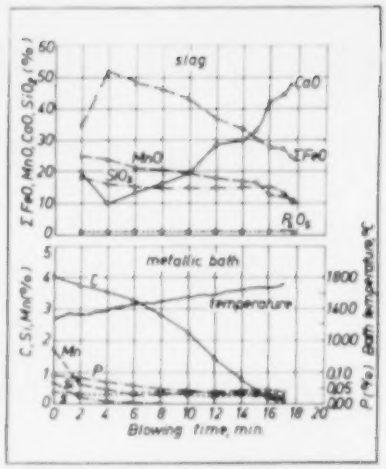


Fig. 2 (left)—LD melt with ore cooling for a mild, killed steel for tubes; tensile strength from 22.2 to 28.8 tons-per-sq-in. Fig. 3 (center)—Same as Fig. 2 with scrap cooling; both after R. Kunz. Fig. 4 (right)—LD melt with scrap cooling; after E. Plöckinger and M. Wahlster.

pct C, as well as Cr-Ni-Mo-V, Ni-Mo, and W-Cr-V steels, have been produced. A total of 47 different types of steels, which were formerly produced only in the electric furnace, have now been included in the program of the LD steel plant.

LD metallurgy

Like other new processes, the LD process is constantly being further investigated by tests, intended to clarify metallurgical questions which keep cropping up continuously.

From the beginning, the melting loss conditions of the bath, being the most important aspect of the metallurgy of the process, have been the subject of numerous investigations. It is difficult, however, to take a regular sample without interrupting the process. On the occasion of the 1959 Austrian metallurgists' meeting, E. Plöckinger reported on successful tests with a 3-ton test vessel[10], in which it was possible to measure temperature constantly, thanks to the installation of a thermocouple in the rim of the crucible bottom. In Fig. 4 Plöckinger shows the development of a normal heat cooled with scrap. There is nothing new to be said about the analyses of the steel, but as far as the slag samples are concerned, he analysed and considered only that part of the slag which really acts as slag, i.e. only the dissolved liquid part. The curves clearly show that, in the beginning, the slag is very acid and becomes basic gradually as the lime dissolves. To the same extent as the basicity increases, the FeO and the MnO contents decrease continuously. The curves clearly show how important it is for a rapid dephosphorization that the lime should dissolve very quickly.

On the basis of his observations, Plöckinger goes on to describe equilibrium conditions for manganese (Fig. 5). First he shows that the curves for K_{Mn} plotted on the basis of the slag analyses correspond to the theoretical lines for acid and basic slags. But, at the beginning of the process there is no equilibrium between the bath and the slag (there is a surplus of FeO required for the high refining rate), which is evident from the curve line two to six. It is not until a slag ratio greater than two has been reached . . . between sample six and eight . . . that the distance from the equilibrium line becomes smaller. After the oxygen supply has been turned off . . . sample twelve . . . the equilibrium between

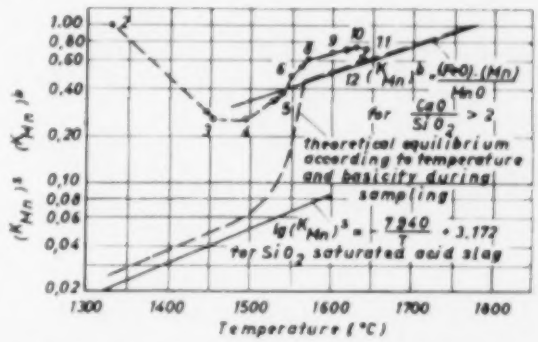

theoretical equilibrium according to temperature and basicity during sampling
for SiO2 saturated acid slag
for CaO/SiO2 > 2
Temperature (°C)

Fig. 5—Alternation of manganese distribution during melting; after E. Plöckinger and M. Wahlster.

the metal bath and the slag is established within a short time, as is to be expected theoretically. This is further proof that LD steel is in no way oversaturated with oxygen.

Conclusions

With the foregoing explanations, I hope that I have made it clear that also outside of North America, the LD basic oxygen steelmaking process is constantly being further developed so as to make use of a wider range of raw materials and produce an ever larger group of steels.

References

[1] Three Years LD Steel: *VOEST*, 1956.

[2] O. Cuscoleca and K. Rösner: Development and the Present State of the LD Process, *J. of Iron and Steel Inst.*, 1959, vol. 192, Part 2, pp. 147-153.

[3] H. Trenkler and R. Rinesch: Applicability of the LD process to Pig Irons showing Elevated Phosphorus Contents, *Stahl und Eisen*, 1958, pp. 883-890.

[4] K. Grünberg, W. Schleicher, and R. Kunz: Steelmaking according to the Process of Blowing Oxygen onto the Surface of the Bath with cooling by Ore, *Stahl und Eisen*, March 3, 1960, pp. 277-282.

[5] S. Ammareller and W. Knorr: The Properties of Carbon Steels and Alloyed Structural Steels produced by the LD Process, to be published by *Stahl und Eisen*.

[6] K. Rösner and A. Wegscheider: Production of Steels of High Strength in the LD Converter, *Stahl und Eisen*, 1956, pp. 1337-1343.

[7] O. Cuscoleca and K. Rösner: Production of Special Steels by LD Process, *Report on Journées Internationales de Sidérurgie*, 1958, pp. 61-70.

[8] O. Cuscoleca and K. Rösner: LD Produces Alloy Steels in Austria, *Journal of Metals*, October 1958, pp. 673-678.

[9] A. Richter: *Gusstahlwerk Witten*, Information furnished to author of this paper personally.

[10] E. Plöckinger: *Berg-und Huttenmännische Monatshefte*, copies 11 and 12, 1959 .

LD STEEL FROM HIGH-PHOSPHOROUS IRON

Written especially for the JOURNAL OF METALS, *this article describes development work by the Aciéries de Pompey in France which permits the production of quality steels from high-phosphorous hot metal by the LD, basic oxygen steelmaking process. The result is that the LD process can now be used for the treatment of most types of hot metal, regardless of silicon and phosphorus content.*

by G. Messin, L. Lambert, and G. Helfenstein

UNTIL now the LD steelmaking process has been limited to the treatment of iron containing less than 0.4 pct P. The possible application of the process to hot metal rich in phosphorus is an interesting one, and such a study was undertaken at the Aciéries de Pompey at the beginning of 1956. Some 1200 heats of 20 metric tons have been tested, and the results of this study are here recounted.

Raw materials

Hot metal at the Pompey plant has an average analysis as follows: 3.6 pct C, 0.5 pct Si, 0.4 pct Mn, and 1.85 pct P. Thus, it is hot metal which is normally treated by the thomas or basic bessemer process. Lime used in the LD vessel is the same as that used in the thomas steel shop; it is ground to −40 mm in order to render it more reactive. Ore utilized for cooling the LD heat is North African iron ore of 52 pct Fe content.

The installation

One of the four converters of the thomas steel shop at Pompey has been modified for use as an LD vessel, as shown in Fig. 1. A feed chute permits lime and ore additions to be made during the course of a blow.

The different positions of the vessel for blowing, deslagging, and pouring are indicated in Fig. 2. Pouring of a heat is done through a tap hole.

All of the operations are controlled from a central pulpit where the following recording instruments are located: oxygen line pressure indicator, oxygen lance pressure indicator, oxygen flow indicator, oxygen totalizer, and flow indicator for lance cooling water. The desired blowing pressure is maintained at a constant level by automatic regulation.

Operating principles

Ideally, the treatment of Pompey hot-metal should meet the following conditions: dephosphorization should be terminated before decarburization begins, in order to terminate the operation at a relatively high carbon content. This requires the forming of a fluid slag, rich in lime, as rapidly as possible, in order to promote dephosphorization in the presence of carbon. The slag should be saleable as phosphate fertilizer, which prohibits the utilization of fluorspar for rapid slag formation. Also, the final slag should not be rich in phosphorus, thus preventing rephosphorization before tapping.

The following method of operation has been developed as a compromise between all of these requirements, and includes two parts:

In the first step, silicon and the major proportion of the phosphorus are eliminated, while as much carbon as possible is retained. This operation is stopped at about 1.5 pct C and 0.2 pct P (See Fig. 3a), and a slag containing about 80 pct of the phosphorus in the charge is removed.

The second step includes an important addition of lime, but is otherwise like an ordinary LD blow. The final slag is rich in lime and in FeO, but it is poor in phosphorus. It is retained in the vessel after tapping of the metal and remains there for the first part of the following heat, in the course of which it is enriched in phosphorus and returns its iron oxide content to the metal.

Low-carbon steel

a.) Charging: Hot metal, scrap, and some lime (4 pct), are charged onto the final slag of the preceding charge (3 metric tons). The hot metal is at a temperature of 1200° to 1250°C. The quantity of scrap charged at this time is about 100 kg per metric ton for a normal hot metal (a final addition of 150 kg of scrap per metric ton of iron is being made after deslagging). Iron ore can be used in place of scrap.

b.) First blow: At a high oxygen pressure, about 35 cu m of O_2 per metric ton of hot metal is blown. During this period the lance is momentarily raised in order to form a fluid slag. The lance is brought back to its normal position as soon as the slag is fluid, which is accompanied by a considerable diminution of red fumes and a modification of the flame color.

The blow is stopped at a metal analysis of 1.0 to 1.5 pct C, less than 0.2 pct P, 0.25 pct Mn, and metal temperature is 1550° to 1650°C. There is usually 8 to 12 pct FeO in the slag. The slag, which does not contain metallic granules, is removed over the lip by inclining the vessel.

Fig. 3 indicates the principal characteristics of

G. MESSIN, L. LAMBERT, and G. HELFENSTEIN are with the Société des Aciéries de Pompey at Pompey (M&M), France.

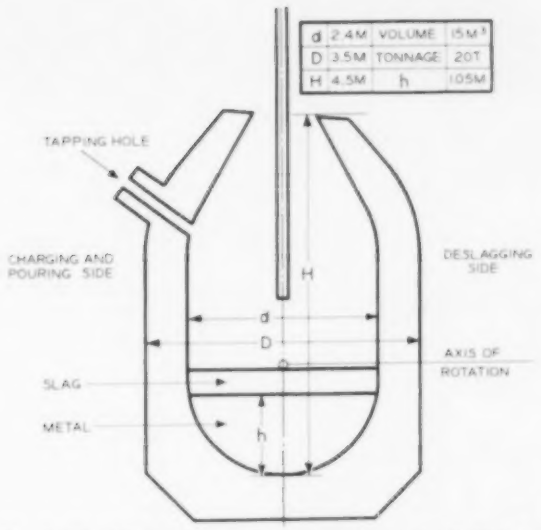
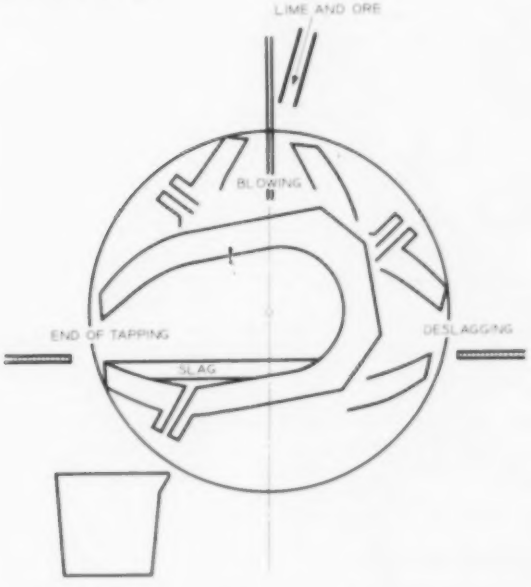


Fig. 1—The LD vessel at the Pompey plant of the Société des Aciéres de Pompey in France. Fig. 2—Different positions of the LD vessel at Pompey.



this step. In the case where manganese content of the charged metal is more than 0.50 pct, the loss of manganese is very low (Fig. 3b). This is due to the fact that the slag of the preceding heat carries manganese oxide and prevents oxidation from the metal. It can also be seen (Fig. 3c) that a high temperature at deslagging permits the removal of a slag low in FeO. It should be noted that the hot metal may have a high silicon content without risk of foaming, as the silica formed is immediately neutralized by the lime-rich slag.

c.) Second blow: Before starting to blow, a quantity of scrap is added. This is calculated as a function of the deslagging temperature and the volume of oxygen yet to be blown, and averages 150 kg per metric ton of iron. It can also be replaced or corrected by ore additions during the course of the blow. Blowing is commenced, again at high pressure, and lime (7 pct) is added as the heat progresses. The blow is stopped when a sufficient

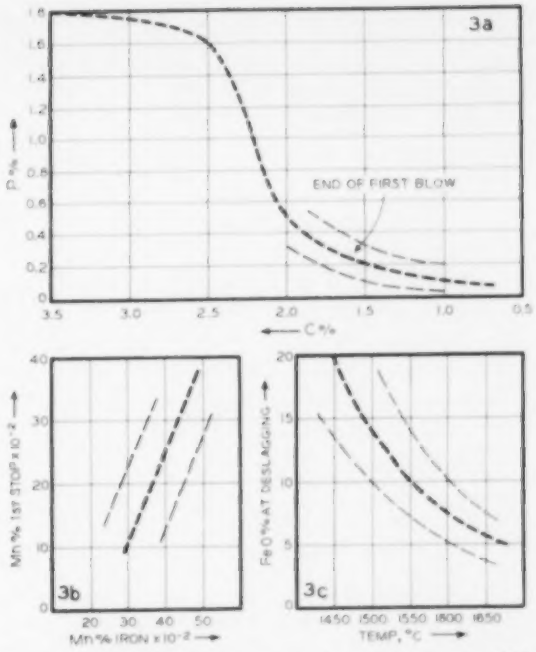
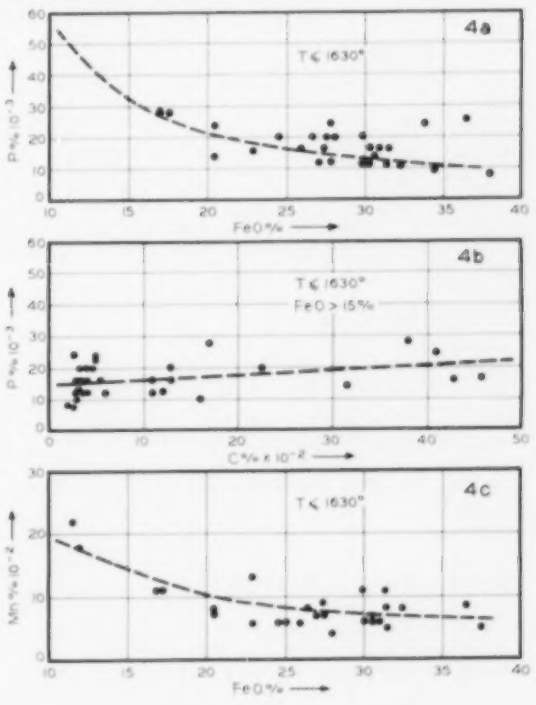


Fig. 3—Principal characteristics of the first blow for high-phosphorous hot metal. Fig. 4—Characteristics of the metal during the second blow.



quantity of oxygen has been blown and flame color is correct. Position of the lance and final oxygen pressure are determined by the desired carbon and phosphorus contents, the latter depending principally on the FeO content of the slag (see Fig. 4).

d.) Deoxidation and casting: Ferromanganese can be added to the vessel, but it is faster to make all additions to the ladle, and this is particularly so for rimming steels. Ladle additions give excellent results, as tapping through a tap hole avoids pouring

slag into the ladle. When slag starts to appear in the ladle, the vessel is righted and is immediately ready for the next heat. The tap hole is plugged by a simple piece of wood.

e.) Time breakdown, tap-to-tap:

charging hot metal, scrap, and lime	7 min
blowing, first step	13
deslagging, sample-taking, and charging additional scrap	9
blowing, second step	8
temperature control and sample-taking	2
tapping and replugging hole	6
Total	45 min

This time requirement should not increase appreciably when the size of the charge is increased.

+0.10 C steel

The second step is modified slightly for production of higher-carbon steel. Violent boiling between slag and metal limits the oxidation of the slag while carbon is greater than 0.10 pct. As the phosphorus content of the bath depends almost exclusively on the FeO in the slag and the bath temperature (Fig 4a), and is nearly independent of the carbon content (Fig. 4b), it is necessary only to modify the blowing conditions in order to diminish the slag-metal boil and permit the slag to retain more FeO. This is done by blowing at a lower pressure.

Precise regulation of the carbon content is accomplished by using an experimentally established decarburization graph. By tapping through a tap hole, the risk of rephosphorization in the ladle is small, as slag-metal separation is excellent.

Tap-to-tap time is slightly increased over production of lower-carbon steels because of the necessity of determining carbon and phosphorus contents, and also because of blowing at a lower rate.

Thermal balance

The subject of thermochemistry of oxygen steelmaking has been treated before* but it should be noted here that the thermal balance is largely influenced by the quantity of CO that is burned to CO_2 within the vessel. In the present study it has been found that the quantity of scrap which may be added varies with blowing conditions, and falls in the range of 20 to 30 pct. This corresponds to 250 to 300 kg per metric ton of metal, and can be replaced with equivalent quantities of ore.

It is therefore possible to consume all of the scrap generated in rolling the steel produced by the process without installing additional melting apparatus.

Metallic balance

While efficiency of metal recovery depends substantially on individual plant practice, it is possible to assume that the only theoretical iron lost will be that contained in the first slag and red fume.

The slag contains an average of 7 pct Fe, which corresponds to about 15 kg per metric ton, and fume losses have been estimated at 10 kg Fe per metric ton. Oxidizable elements (C, Mn, Si, and P) amount to about 62 kg, so that 913 kg of metal should be theoretically recovered from a metric ton of charged hot metal, resulting in 91.3 pct recovery. Of course, efficiency will be increased by charging scrap and/or ore.

Oxygen balance

Losses of oxygen are confined to oxidation of iron which is lost in slag and in red fume. Slag losses are low, since the first slag is low in iron and the second, although high in iron, is used in the subsequent heat. Total oxygen consumption is on the order of 60 cu m per metric ton of hot metal, including both gaseous oxygen and combined oxygen from the ore.

Economics

It has been shown above that the metallic recovery of the process is very good; consumption of lime, less than 110 kg per metric ton of iron, is low, and the consumption of oxygen is equally low. All of these factors, of course, will tend to reduce processing cost. However, the duration of the operation is substantially longer than for the treatment of low-phosphorous hot metal—about 50 pct greater. Therefore, it requires greater investment in capacity and labor for a given production.

Consumption of refractories has not been determined with precision, as this requires a long industrial-scale operation. However, the MgO content of the slag, and comparison of the life of linings in the thomas and LD vessels shows that the consumption of dolomite should be below 18 kg per metric ton.

Steel quality

At the end of the second blow, the steels produced during this study have been almost identical to steels produced from low-phosphorous iron. It should, therefore, follow that these steels should have the same good properties as standard LD steel. This has been borne out in tests conducted on the steels with carbon varying from 0.05 to 0.20 pct for rimming grades and from 0.05 to 0.50 pct for killed steels. Tests were conducted for deep drawing qualities, weld bend, Charpy impact properties, and microstructure, and in all cases quality was at least equivalent to open hearth grade.

Conclusions

Results obtained at Aciéries de Pompey substantially enlarge the domain of applications of the LD process, which may now be used for any hot metal, regardless of silicon or phosphorus content.

The method of retaining the final slag for the first step of the following heat limits iron losses and oxygen and lime consumption, thereby reducing processing costs. Moreover, the process is not limited to producing steels of low carbon content, but can also be used for the production of medium and high-carbon steels and low-alloy steels.

With these encouraging results in hand, Aciéries de Pompey has decided to improve this installation by providing mechanized equipment for handling lime and ore, and by installing apparatus for removing dust from the fumes. This small installation will then be capable of producing 6000 metric tons per month. In a second stage of expansion, Aciéries de Pompey plans on installing a new LD steel plant with two vessels, which will substitute for the old open-hearth plant.

* W. O. Philbrook: *Thermochemistry of Oxygen Steel*, JOURNAL OF METALS, July 1956, p. 477.

PNEUMATIC PROCESSES FOR CONVERTING HIGH-PHOSPHOROUS IRON

In Europe, the application of pneumatic processes for converting high-phosphorous hot metal have increased considerably. This is evident if only the various bottom-blowing processes are considered, but it is still more obvious if top-blowing processes are taken into account. This paper presents recent information on these developments, with particular emphasis on the LD-AC process for top blowing with oxygen containing powdered lime.

Condensed from a paper by P. Coheur

In Europe, three leading techniques of bottom blowing hot metal are currently in use; they differ as to the nature of the blast, and include atmospheric air, oxygen-enriched atmospheric air, and gaseous mixtures, essentially composed of oxygen and steam.

Up to now, some half-billion tons of low-carbon steels have been produced using atmospheric air. These steels, which are quite suitable for numerous purposes, contain an average of 0.0090 to 0.0120 pct N, 0.045 pct P, and 0.035 pct S.

From the point of view of economics, blowing with atmospheric air is characterized, in contrast to the classical open-hearth and electric processes, by lower capital and operational costs and by a much shorter time of elaboration. On the other hand, the process requires a hot metal of a narrow range of phosphorus and silicon content and permits the melting of only a relatively small quantity of scrap.

When quantities of oxygen at sufficiently low prices became available from tonnage oxygen plants, steelmakers used the opportunity to enrich atmospheric air with oxygen. Enrichment of 25 to 40 pct resulted in the following improvements over the classic pneumatic process:

1) a 20 to 25 pct reduction in the nitrogen content of the steel produced and, to a smaller extent, the phosphorus content;

2) an increase in scrap consumption;

3) a 30 to 40 pct decrease in the conversion time; and

4) a 10 to 20 pct increase in production capacity.

The spectacular development of the market for flat products which arose after World War II, forced steelmakers to produce new grades of steel having a higher cold ductility than could be obtained by blowing with atmospheric air or oxygen-enriched air. In this regard, it was necessary to lower considerably the nitrogen and phosphorus content of steel. The recourse for steelmakers utilizing pneumatic processes was blowing with gaseous mixtures, such as oxygen and steam, and establishing a double-slag practice. The steel produced according to this method, called the OV process, contains about 0.0020 pct N, 0.020 pct P, and 0.020 pct S. It has cold ductility properties at least equal to those of open-hearth steels.

P. COHEUR is a professor at the University of Liège and director of the Belgian National Metallurgical Research Center. This paper was originally presented at the 1960 AIME Annual Meeting.

Special bottom-blowing processes

1) Dual Process

The evolution of metallurgical reactions occurring in a basic bottom-blown converter is characterized by the fact that carbon elimination precedes that of phosphorus, regardless of whether the oxidizing medium be atmospheric air, enriched air, or oxygen-steam mixtures. This results from the fact that phosphorus elimination is carried out in two stages:

$$2P + 5\,O = P_2O_5 \qquad [1]$$

$$P_2O_5 + 4\,CaO = CaOP_2O_5 \qquad [2]$$

and that the second reaction, under industrial conditions, starts only when the slag becomes liquid. This occurs at the point that carbon oxidation provides the metal bath with sufficient heat.

In order to hasten dephosphorization and prevent an exaggerated decarburization of the metal bath, diverse proposals have been advanced. All of them aim at the liquefaction of slag at an early stage. Among these processes, one proposed by H. Bansen in 1926[1] consists of increasing the amount of heat supplied to the metal bath by burning a portion of the escaping carbon-monoxide. This is most easily carried out by an oxygen lance introduced through the top of the converter.

In 1955/56, the Belgian National Metallurgical Research Center (CNRM) decided to verify this proposal and thus carried out heats by blowing enriched air through the bottom of the converter while simultaneously blowing oxygen through the top. This was done at the Espérance-Longdoz works in Belgium.

Although the concept may be theoretically attractive, in practice and under operational conditions in which we were placed, it was not possible to reach the desired goal. Dephosphorization was no faster, and there was no change in the final carbon

content of the bath. However, the process has the advantage of melting an additional quantity of scrap, varying from 0.60 to 0.75 lb per cu ft of O_2 blown through the lance, and 0.30 to 0.38 lb per cu ft of O_2 blown through the bottom. These figures correspond exactly to the heat resulting from the combustion of carbon monoxide with the oxygen blown through the lance.

2) Phoenix Lance[3]

When conversion is carried out by means of atmospheric air or oxygen-enriched air, it appears that the nitrogen in the metal bath varies with time and increases rapidly when the carbon is relatively low and when dephosphorization is increasing. This results from the fact that, during the last minutes of blowing, the oxygen of the blast combines with phosphorus, causing the gas escaping from the bath to carry a considerable quantity of nitrogen. The percentage of carbon monoxide is very low, and the temperature is on the high side.

Engineers of the Phoenix-Rheinrohr firm in Germany tried to prevent this abnormal nitrogen concentration by carrying out dephosphorization by means of an oxygen lance. They proposed a three-stage process:

1) conversion is conducted in the normal manner to an avg of 0.1 to 0.4 pct C;

2) the converter is tilted, an oxygen lance is introduced through the top, and phosphorus elimination is achieved with industrial oxygen; and

3) when the phosphorus content reaches 0.2 to 0.3 pct, the lance is withdrawn, the converter is raised again, and the conversion is finished according to the classical technique in less than 1 min.

With this technique, known as the Phoenix-Lance, steels have been produced containing 0.0020 to 0.0050 pct N and 0.025 to 0.030 pct P. Desulfurization is on the order of 70 to 80 pct.

In its new thomas steel plant in the Ruhr, Phoenix-Rheinrohr has equipped two converters for this process. However, it is still too early to express any opinion about its future exploitation.

Top-blowing processes

1) LD

As far as phosphorous . . . 1.5 to 2 pct P . . . and semi-phosphorus . . . 0.6 to 1.5 pct P . . . hot metals are concerned, the LD process was faced with difficulties which had to be met by special blowing techniques.

One technique, proposed by metallurgists from the Société des Aciéries de Pompey in France in collaboration with engineers of VOEST in Austria, is a two-slag process using crushed lime. It is described in detail in an article written by metallurgists from the Pompey plant, and appearing in this issue of the JOURNAL OF METALS.

2) LD-AC

A second modification of the LD process to permit the treatment of high-phosphorous hot metal consists of injecting pure oxygen containing powdered lime onto the surface of the bath through a lance. This technique was studied by IRSID, the French ferrous metallurgy research institute, at the Denain steelworks in France[4], and quite independently, by metallurgists of the ARBED firm in Luxembourg working in close collaboration with CNRM. In the following discussion, we shall consider only the results obtained by ARBED and CNRM, which led to the development of the LD-AC process.

P. Metz at the Journées Internationales de Sidérurgie held in Liège, Belgium, in June 1958, described the installation at ARBED and presented the first results obtained[4]. And during the Annual Meeting of The Iron and Steel Institute, held in London in May 1959, he submitted the results obtained on an industrial scale, operating the process on a 24-hr basis.

At the present time, more than 2000 heats from a 26-ton converter representing more than 50,000 tons of steel have been produced. The following items summarize the results obtained thus far:

1) From the operational point of view, stress should be laid on the foaming state of the slag, which can be provoked, adjusted, and controlled within narrow limits. This is most advantageous for controlling the conversion, reducing the projections, and increasing the metallic yield.

2) As to the evolution of the chemical and physical reactions, in contrast to the basic bessemer performance, dephosphorization and decarburization take place simultaneously. The result is that the state of oxidation of the metal at the end of the elaboration is controlled, as in the open-hearth process, through the carbon activity of the metal bath. In a more explicit way, Fig. 1 shows the Vacher and Hamilton C x O relation for $P_{CO} = 1$ atm, and above it, a curve relating to the open-hearth process. Fig. 1 also shows a mean curve for a series of 200 consecutive LD-AC heats. The curve is located somewhat below that of the open-hearth steel and even approaches the Vacher and Hamilton curve when the carbon content becomes less than 0.05 pct.

3) As for the chemical analysis of the steel produced, the nitrogen content depends upon the purity of the oxygen blast. Hence, with 95 pct O_2, the nitrogen content of the steel is approx 0.0050 pct, while with an oxygen of 99.5 pct purity, the nitrogen content of the steel is 0.0025 pct.

Desulfurization during the elaboration is particularly high, reaching to 70 pct. This then permits steels containing 0.015 to 0.020 pct S to be produced without any difficulty.

The phosphorus content of the steel can easily be brought within 0.010 to 0.020 pct. This is achieved with two calcic slags; the first is removed when the phosphorus content of the bath is between 0.100

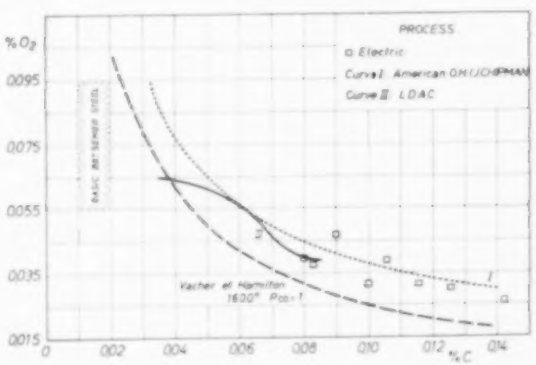


Fig. 1—Vacher and Hamilton C x O relation for $P_{CO} = 1$ atm as compared with the LD-AC, electric-furnace, and open-hearth processes.

and 0.200 pct. This technique is identical to that used in the basic bessemer operation, except that, in the case of LD-AC, the carbon content of the bath at the time of the first slag removal is 0.7 pct, while in the basic bessemer process it is 0.02 pct. Furthermore, the second slag, when operating with a tapping hole, may be kept in the converter and used in the following heat.

4) In regard to the operating costs of the process, the following information for a converter without a tapping hole is of value:

a) scrap consumption is about 600 lb per ton of hot metal, and scrap may be wholly or partially replaced by ore;

b) lime consumption is on the order of 210 lb per ton of hot metal;

c) oxygen consumption is 1920 cu ft per ton of hot metal;

d) iron yield of the operation is about 90 pct, due to the large quantity of scrap added and the low iron losses in the slag;

e) the yield of manganese for deoxidation is on the order of 75 pct, because of the low oxidation stage of the metal at the end of the operation;

f) the rate of conversion is 1.75 ton of steel per min, but this rate can be increased under better operating conditions; and

g) the refractory linings of the converter are subjected to more severe conditions than in the case of bottom blowing. With conventional rammed dolomitic linings, the life of the refractories, although reduced by 30 to 40 pct, is sufficient for economic operation. In order to prolong this life, one solution would be to adopt the same refractory lining as is used in the LD process, i.e. magnesite refractory linings.

On the basis of the above data, and assuming a pig-iron: scrap cost ratio above 1.7, it would seem that the operating costs for the LD-AC process in the Belgian and Luxembourg plants would be on the same order as those encountered in the bottom-blowing basic bessemer process using oxygen-enriched air.

5) For determining the mechanical properties of the steels, we undertook numerous studies, not only in the laboratory, but also in industrial applications among customers. These studies dealt with low-carbon, mild, and high-carbon steels, and rimmed, semi-killed, and killed steels. Cold ductility, transition temperatures, and inclusions were given particular attention.

We compared the steels obtained by the LD-AC process with those produced by oxygen-steam blowing, and the Kaldo, open-hearth, and electric furnace processes. The conclusion drawn was that, with a given chemical analysis and rolling technique, the LD-AC steels offer mechanical properties at least equal to those of steels produced by these other processes.

6) The LD-AC process, in spite of its newness, enjoys at the present time in Europe, a great deal of success. Several firms in Belgium, France, Germany, the UK, and Luxembourg have decided to equip their steel plants for this process. One of them is already in operation.

7) Currently a number of studies, designed to extend the industrial application of the LD-AC process, are underway.

In one area, research on increasing the scrap consumption is being pursued. Two techniques are advisable. The first consists of increasing the amount of combustible elements in the system. This can be done by means of solid fuel additives. But liquid or gaseous fuels may also be employed by providing the oxygen lance with an additional tube, concentric or centric; it would be, in fact, a special burner working with a high excess of oxygen.

The second technique is based on the previously-mentioned idea of H. Bansen for burning the excess carbon dioxide gas with an additional supply of oxygen. This technique is soon to be employed in a steelplant, which will use a special lance composed of two concentric tubes. The central tube will be used for the introduction of oxygen and powdered lime, while the outer tube will be used to provide the necessary oxygen for the combustion of carbon monoxide.

Research is also underway on the application of the LD-AC process to semi-phosphorous and non-phosphorous hot metal. There is ample *a priori* evidence that the LD-AC process can also be used for these types of pig iron. Interest with respect to the LD process would lie in an easier control, a higher flexibility of the operation, and possibly in lower production costs. Small-scale experiments have already been carried out, and one steel plant is actually equipping itself with such an installation. It will start operation during 1960.

Conclusions

In conclusion, it should be pointed out, first, that in Europe the pneumatic processes of converting high-phosphorous hot metal show a continual increase in application. This is true not only if the absolute tonnages of steel are considered, but also if the percentage of the total steel production is taken into account. This tendency is evident if only the basic-bessemer bottom-blowing processes are considered, and it is still more obvious if the top-blowing processes are taken into account.

As to the bottom-blowing processes, it is important to notice that the conventional technique of blowing with atmospheric air is actually used and will still be used by many companies. This follows from the fact that the quality of the steel produced is perfectly adapted to numerous applications and that the operating costs are the lowest under the economic conditions under which the producing plants operate.

The tendency today, however, is to use oxygen-enriched air or oxygen-steam mixtures, mainly because of the relative cost of pig iron and scrap and the necessity for some steel works to produce steels with high cold-ductility properties.

As to the conversion of high-phosphorous hot metal by top blowing through the LD-Pompey or the LD-AC processes, the quality of the steel produced is equal to that of oxygen-steam or open-hearth steels. Thus, the major reason for the advance of these processes is one of economics and also the possibility of handling semi- or low-phosphorous hot metal and producing steels not adapted to output by the bottom-blowing converter.

References

[1] H. Bansen: *Stahl und Eisen*, 1926, p. 1279.

[2] H. th. Brandt: Phoenix-Lance Steelmaking, JOURNAL OF METALS, February 1959, p. 118.

[3] B. Trentini and M. Allard: O.L.P.: Oxygen, Lime-Powder Injection, A New Steelmaking Process, JOURNAL OF METALS, July 1958, pp. 466-471.

[4] P. Metz: New Research on Processes for the Conversion of Iron with Pure Oxygen, *Revue Universelle des Mines*, 1958, pp. 501-511.

Notes on ALGOMA'S LD STEEL PLANT

The following two papers present operating data on the LD, basic oxygen steel plant of the Algoma Steel Corp. in Canada. The wide variety of steels produced by this basic oxygen steel plant is of particular interest.

Photo by David Cain

1. Low to High Carbon Steels

by C. C. Benton

Production of steel using the LD, basic oxygen process at Algoma began on November 18th, 1958. The process had been proven in the production of low-carbon steels, but due to the particular product mix at Algoma, it was necessary, in order to realize the full productivity of the basic oxygen plant, to produce all grades that were produced in the open hearths.

Immediately after the commencement of operations, practices were established for the production of all grades of steel ranging from 0.03 pct max C to 1.05 pct C, including some low-alloy grades. Some 73,000 tons of medium-and high-carbon steels were produced at Algoma in the first 12 months of operation. Further refinements in practices for making these steels are in progress, and are considered a necessity, since it is our opinion that additional knowledge is yet to be acquired in the production of steel by this process.

During the blowing period, the flame issuing from the mouth of the vessel decreases quite suddenly at about 0.06 pct C, as in the bottom-blown pneumatic processes; thus, there is no practical difficulty in meeting carbon specifications for low-carbon steels. Indications of a decrease in the flame at the furnace mouth may be seen as high as 0.25 pct C, and, with experience, observation of flame characteristics may be used with a considerable amount of success in predicting carbon contents up to that level. Above 0.25 pct C, the relation between flame characteristics and carbon is imperceptible to visual observation.

Methods of producing steels above 0.25 pct C may be divided into two categories:

a) Blow to 0.25 pct C or lower and then recarburize either in the furnace or in the ladle to the desired level;

b) Employ some means other than observation of the flame to estimate the carbon and thereby blow to a carbon level near that of the carbon specified.

The first method has several serious disadvantages, among which are excessively long blowing times, high oxygen consumption, erratic temperatures, and uncertainty of obtaining the carbon content desired. At Algoma all steels above 0.15 pct C are produced by completing the blow within the specified carbon range.

The charge

The metallic charge at Algoma is composed of scrap, hot metal, and iron oxide, the latter usually in the form of sinter. In a given type of charge, the weight of scrap used is constant, and control over

C. C. BENTON is with Algoma Steel Corp. Ltd. at Sault Ste. Marie, Ontario, Canada. This paper was presented at the 43rd National Open Hearth Steel Conference in April 1960.

bath temperature is exercised by varying the amount of iron oxide in accordance with changes in the silicon and manganese content of the hot metal. A typical hot metal analysis would be: 4.5 pct C, 0.90 pct Si, 0.038 pct S, 0.180 pct P, and 2.2 pct Mn. Silicon analysis is reported for each torpedo ladle, and there are up to three torpedoes for each blast furnace cast.

Other factors influencing the amount of iron oxide used for temperature control are the hot metal temperature and any undue delay before charging the furnace. Hot-metal temperatures are measured by inserting an immersion thermocouple into the metal in the ladle. Operating experience has shown that the iron oxide used possesses three times the cooling properties of scrap; thus the weight of scrap plus three times the weight of oxide may be termed *scrap equivalent* in the charge.

The amount of scrap charged is usually between 12 pct and 25 pct of the total metallics charged, while scrap equivalent may be as high as 40 pct. The limitation of scrap charged is due to operational requirements aimed at minimizing charging time. It has been found, however, that, due to the comparatively low steel temperatures required and short blowing times for high-carbon steel, some difficulty may be experienced in obtaining scrap solution unless careful attention is given to the size and weight of the pieces of scrap charged.

As an example of typical charge structure at Algoma, in a total metallic charge weight of 246,000 lb with 1 pct Si in the hot metal, 30,000 lb scrap might be used and 18,000 lb of iron oxide by volume, with the remainder of the metallics charged as hot metal.

It is to be noted that large quantities—sometimes as much as 26,000 lb—of iron oxide are included in the charge. The oxides used are of high purity, with an avg iron content of 67 pct and an oxygen content on the order of 27 pct. On this basis, 2000 lb iron oxide would contain 54 lb oxygen, which, at stp, has a volume of 6048 cu ft. Thus, 18,000 lb of iron oxide would contain approx 54,400 cu ft of oxygen at stp, which is a substantial contribution to the amount of oxygen entering the furnace.

Production practices

Operators of basic oxygen furnaces are well aware that bath reactions are strongly affected by the characteristics of the oxygen stream. The interrelated effects upon rates of bath reactions of factors such as; lance-nozzle design, oxygen flow rates, bath depth and diameter, and the distance between lance nozzle and bath surface, are of great importance and are worthy of intensive investigation. Fundamental studies have not been made at Algoma, but sufficient knowledge has been obtained to set up practices for each grade above 0.30 pct C. On turning the furnace down for sampling, it is possible in the majority of cases to obtain an accuracy of ± 10 points of the aimed carbon. It is, thus, possible to tap these steels with the use of little or no recarburizer.

Early in the experimental work leading to the production of high-carbon steels, it was observed that unless measures to the contrary were taken at high-carbon levels, the FeO contents of the slags were generally low and phosphorus contents of the steel tended to be disturbingly high. For similar reasons, residual manganese levels would be expected to be high at high-carbon levels. This is a matter of importance in our operations, since an appreciable portion of high-carbon steels are made to a general specification of 0.80 to 0.90 pct C and 0.20 to 0.45 pct Mn. It should be borne in mind that the manganese load entering the furnace is high, since 83 pct of the charge may contain 2.0 to 3.0 pct Mn. As a result, at 0.10 pct C, the manganese content of the bath is typically on the order of 0.30 pct.

Operating Data on LD, Basic Oxygen Furnaces

	Year 1959	Jan. 1960	Feb. 1960
Tons produced	572,868	66,724	60,397
Avg heat size	98.5	102.5	101.8
Avg heat time	1'-11"	1'-03"	1'-05"
Tons per hr tap-to-tap	83.2	98.8	95.2
Grades produced, under 10 C	246,300	28,606	21,200
11 to 30 C	248,800	33,135	35,675
31 to 50 C	41,900	2,093	2,182
51 C and Over	35,868	2,890	1,340

Charge Composition on LD, Basic Oxygen Furnaces

	Year 1959	Jan. 1960	Feb. 1960
Scrap, pct	14.2	19.3	19.2
Oxides (Metallics), pct	4.3	3.0	2.4
Hot Metal, pct	80.9	77.2	77.8
Alloys, pct	0.6	0.5	0.6
Lime, lb per ingot ton	119.9	132.8	134.8
Spar, lb per ingot ton	1.3	3.0	3.2
Oxygen, cu ft per ingot ton	1,686	1,667	1,701

It has already been established that adequate basicity in the slag was provided by charging lime in the proportion of 2.75 contained CaO to 1 of the silica derived from the iron oxide charged and from oxidation of silicon. It was also necessary to produce reasonably high FeO contents in the slag at high-carbon levels to attain good dephosphorization and, if required, low residual manganese levels. It was essential, therefore, to take slag condition into consideration in developing practices for each grade.

Experience has shown that increasing carbon levels may, nevertheless, be accompanied by a slight increase in phosphorus levels. Our results show an avg phosphorus for steels under 0.30 pct C to be 0.10 pct; for steels between 0.30 and 0.50 pct C, 0.012 pct; and over 0.50 pct C, 0.016 pct P.

Algoma's steelmaking methods, however, do not differ in essentials from those employed in other plants. Scrap, iron oxide, and hot metal are charged, and the oxygen blowing begins. Lime is added and blowing continued until the desired steel analysis is obtained. Steel temperatures are measured by immersion thermocouple. Samples of steel are taken for carbon and manganese, and a slag pancake is poured for visual estimation of FeO.

With the exception of copper, nickel, and molybdenum, which are added to the furnace at charge, no ferroalloys, such as silico-manganese, ferrosilicon and ferromanganese, are added to the furnace. All alloying additions, except copper, nickel, and molybdenum, are made to the ladle during tapping. Recarburizing agents, such as petroleum coke, are added to the ladle, if required. The avg amount of recarburizing agent required for steels above 0.30 pct carbon is 1.7 lb contained carbon per ton of steel.

Conclusion

Operation of LD, basic oxygen furnaces at Algoma since November 1958 has effectively demonstrated some of the flexibility of the LD process

with respect to grades of steel that can be produced. All grades made by the open-hearth process at Algoma are also made by the basic oxygen process. Steels within the ranges of 0.03 to 1.05 pct C, 0.15 to 1.65 pct Mn, up to 1.65 pct Ni, 0.24 pct Mo, 0.50 pct Cu, and 1.10 pct Cr, and including resulfurized and rephosphorized grades, have been produced on a routine basis.

The grades of steel produced include rimmed, semi-killed, and fully-killed, fine-grained steels for severe forging and upsetting applications. In all cases the quality of the steel has been found to be equal to or better than open-hearth steel of the same grade.

2. Experience with Furnace Linings

by F. C. Muttitt

Algoma's LD, basic oxygen steelmaking plant consists of two 60-metric-ton eccentric-cone furnaces with an inside-shell diam of 16 ft 1 in., and an overall height of 25 ft.

From the beginning of operations in November 1958 until the end of February 1960, 49 lining campaigns were completed. During this period a large number of variables were introduced, any of which could have had a significant effect on lining performance. Among these variables were: 1) rate of operation, ranging from four heats per day in the early stages to the present rate of up to 24 heats per day; 2) heat size, which began at 75 tons, and in recent months has exceeded 100 tons; 3) oxygen flow rate, and lance design; 4) charge composition; and 5) type of lining material, and design and thickness of lining.

As a result of this lack of uniformity in conditions, it has not been possible, with the number of linings involved, to establish any reliable comparisons of performance by type of lining material, or by design of lining. It is our purpose, rather, to describe our experience to date, and to express some of our present thoughts regarding the most desirable lining features for our conditions.

F. C. MUTTITT is with Algoma Steel Corp. Ltd. at Sault Ste. Marie, Ontario, Canada. This paper was presented at the 43rd National Open Hearth Steel Conference in April 1960.

Original design

As originally designed, the furnaces were equipped with burned magnesite tank linings of 18-in. thickness in the bottom and 4½-in. thickness in the cylindrical *barrel* section. No tank lining was provided in the hemispherically-shaped *cone* section. Later modifications to the tank lining have included removal of the upper 9-in. course of the bottom, in order to provide additional furnace working volume, and extension of the 4½-in. lining through the cone section. Since working linings are removed with water, tank lining repairs and replacements are made with hydration-resistant, low-iron magnesite brick.

In general, owing to the necessity for steelwork repairs, the upper 3 to 5 ft of the cone tank lining is replaced on each reline. Barrel section tank linings are patched periodically, totalling to date some 60 pct of the original count. No repairs have been required to the bottom tank linings.

The original working lining consisted of a 16-in. bottom, barrel section of 18-in. brick backed up with a 4-in. rammed layer, and cone section of 16-in. brick with the same 4-in. rammed layer. These early linings were all of the conventional tar-dolomite-magnesite type, containing approximately 58 pct MgO. Five linings of this composition and design were installed and provided an avg life of 175 heats, with a lining material consumption of 17 lb per net ton. During this period, heat size averaged 85 tons, oxygen flow rate was 5000 cfm, and production was at the rate of 12 heats per day.

Modifications

Failure of these linings in every case occurred in the cone section, and attempts to prolong service through hot patching met with little success. As a result, on the subsequent eleven linings, the rammed backup was eliminated in the cone section, the tank lining was extended to the full height of the furnace, and the working lining thickness in this area was increased to 22 in. and later to 24 in. At roughly the same time as these modifications to lining design were made, other operational changes occurred which tended to cloud the results. Heat size was increased to 98 tons and oxygen flow rate to 6000 cfm, while production rate during this period averaged 18 heats per day. However, it was apparent that the critical wear area was now located in the *belly* of the furnace—the area below the tap-hole which on the Algoma furnaces is the point of scrap and hot metal impact during charging. The average life of this series of linings was 168 heats, with a consumption rate of 18 lb per net ton.

The next approach to the development of a balanced lining involved the installation of an increased lining thickness in the belly zone. This *pilaster* extended for one-third of the furnace circumference centered on the tap-hole, and from the furnace bottom to tap-hole level. Rammed backup was eliminated in this section, and brick thickness increased to 24 in. The remaining two-thirds of the barrel was unaltered at 18 in. of brick with 4 in. rammed backup. Since the cone appeared no longer to be a severe wear area, and since gun maintenance had been developed to the point where service on this

area could be appreciably prolonged if necessary, the thickness of the cone lining was reduced to 18 in. with no rammed backup.

Storage problems

This general arrangement of lining design was continued over the course of some 30 campaigns, extending through the summer and fall of 1959. During this period of relatively stable operating conditions (production rate was further increased to a maximum of 24 heats per day) and using this uniform lining design, we experienced a sharp reduction in lining life, to 150 heats and 20 lb per net ton in June and July, and to 127 heats and 24 lb per net ton in August and September. While a good many trial compositions were tested in this period, the drop in performance applied equally to the regular brands and compositions, leading us to suspect a deterioration in brick quality as a result of hydration during the warm and humid months. In view of the rapid turnover of linings during full operation, and our relatively remote location in relation to the sources of supply, it is difficult to ensure an adequate supply without encountering occasional prolonged storage times. The obvious solution would, of course, be a hydration-free composition comparable to the present materials in terms of performance and cost, and certainly some progress is being made in the development of such a product; otherwise some type of controlled-atmosphere storage may have to be provided.

Also during the period under discussion we undertook a number of split-lining trials involving alternate compositions, while leaving the lining thickness and design unchanged. Included among these were several linings of stabilized dolomitic magnesite, which, while largely eliminating the shipping and storage problem, did not equal the performance of the lower-silica compositions of dolomite with magnesite fines. The presence of 2.0 to 2.5 pct Mn in our hot metal would be expected to contribute to the more rapid erosion of such high-silica compositions.

A second series of split trials involved the use of the same stabilized dolomitic magnesite, with and without added carbon. These tests indicated some advantage in the addition of graphitic carbon, although the optimum carbon content, beyond which mechanical strength is sacrificed, was not established. Further full lining trials of the most promising added-carbon compositions are planned.

Following the period of poor lining performance in the summer and fall of 1959, service began to improve gradually, reaching an average of 153 heats and 19 lb per ton in December. This improvement to some degree confirmed our suspicions regarding the effect of weather on lining condition. No change was made in lining details in this period, while in November heat size was increased to 103 tons and oxygen flow from 6000 cfm to 6500-7200 cfm, depending on lance size.

The present lining

As lining life improved, it became apparent that the use of the pilaster construction had largely eliminated failures in the belly section. The area of most severe wear was now located at the 3 o'clock and 9 o'clock positions at trunnion ring level (the center line of taphole being regarded as the 6 o'clock position), and almost all linings in this period were removed, owing to failure at these locations. While it had been possible, through gun maintenance, to extend the life of the cone or belly sections, we were unsuccessful in our efforts to hot patch these trunnion areas. Consequently, a further modification in lining design was made, involving the elimination of the 18-in. brick, the 4-in. rammed portion of the barrel lining, and the replacement with 24-in. brick throughout. Thus, our working lining became, and remains at this date, an all-brick construction, with 16-in. thickness in the bottom, 24-in. in the barrel, and 18-in. in the cone. Two key shapes in each brick length are required, a total of six shapes, and working-lining weight is approximately 155 tons. The only rammed material used is that required to level off sidewalls after installation of the bottom, and to install the spiral starter on which the side lining is constructed. We have seen little or no evidence of the advantage of the rammed layer in providing tighter linings, while its use appreciably prolongs installation time. Moreover, we believe the service obtainable on the rammed material is very much less than that on an equivalent thickness of added brick.

Lining life in January, using this design, avgd 187 heats and 17 lb per ton, and in February 182 heats and 17 lb per ton.

Burn-in procedure

Some degree of lining damage has frequently been encountered as a result of shelling during burn-in. In the regular burn-in procedure; 1200 to 1500 lb of hot coke is distributed over the bottom, the lance lowered to the 15 ft level, and oxygen introduced at a pressure of 5 psi. The pressure is varied to maintain a rate of temperature rise of 100°F per min, as registered by a thermocouple through the taphole on a high-speed recorder. A wide variation from one lining to another has been noted on the speed and violence of the tar ignition, and thus on the oxygen pressure required to maintain the rate of temperature rise. In our early procedure, after a temperature of 2000°F was reached, the furnace was held at or above this level for 2 hr before charging; and much of the shelling, which usually amounted to a 1 or 2-in. layer over most of the lining, occurred during this holding period. Present practice is to hold temperature at the 2000°F plus level for 10 to 15 min before charging, resulting in a total time from oxygen on to tap first heat of 80 to 90 min. This procedure has had no damaging effect on lining condition.

Conclusions

While we do not believe we have reached the ultimate in lining design for minimum lining cost per ton, the present lining appears to provide reasonably well-balanced wear under Algoma's operating conditions, while removing much of the danger of lining failure before the alternate furnace is ready for operation. In certain cases where extensive repairs to furnace steelwork are required, an elapsed time of five days or more may be required to complete removal and replacement of lining and burning in. As a result, a restriction is placed on the extent to which the lining thickness may be reduced in an effort to improve consumption figures, while still providing a reasonable safety factor in furnace availability.

SOVIET LD STEEL INSTALLATION

Through the courtesy of the Iron and Coal Trades Review, *London, comes this translation of an article by S. G. Afanas'ev and G. N. Kozin originally appearing in* Metallurg *1959 (No. 11). Described is a top-blown basic-bessemer plant at the Krivoi Rog steel works in the Soviet Union.*

The converter plant at the Krvioi Rog iron and steel works is planned for top-blowing pig-iron with pure oxygen through a special water-cooled lance. The two converters have a volume of 1554-cu-ft with the following dimensions: internal diam, 11 ft 6 in.; height from bottom to lower lip of mouth, 17 ft 6 in.; internal diam of mouth, 6 ft; overall thickness of lining, 18 to 20 in. The lining is completed in magnesite-chromite brickwork.

Hot metal is poured into the converter from a ladle placed on a transfer car (Fig. 1). Delivery and pouring of the metal into the vessel is done by remote control.

In the shop, two 1300-ton mixers are installed. There are two hot-metal cranes of 130-ton capacity and a machine to fettle slag in the ladles. There is also a device for the recovery of graphite, liberated during the pouring of the hot metal from the mixer and during the ladle fettling.

Materials handling

Ore, limestone, bauxite, and ferromanganese are kept in a covered stockyard, equipped with two 10-ton magnetic grab cranes of 53-cu-ft capacity. Ore and bauxite are moved by the grab crane through an intermediate 920-cu-ft bunker into skips of 70-cu-ft capacity and delivered by electric locomotives.

The limestone is transferred to the lime-burning shop where there are four gas-fired shaft kilns of about 5000-cu-ft capacity. The gases from the lime kilns pass through a gas-cleaning plant and are discharged through a stack into the atmosphere. In order to avoid undue breakage of the screened lime, it is loaded into 123-cu-ft skips and transported by flat-platform railway trucks. At another point the skips are transferred either to a special platform or directly to the converters by a 20-ton capacity electric locomotive.

Between the two converters is installed a 5-ton bridge crane, which takes the skips from the electric locomotive and discharges them into bunkers located at a level of 74 ft. Each converter has three bunkers, one of 530-cu-ft capacity for ore, one of 780-cu-ft for lime, and one of 530-cu-ft for bauxite. Under the bunkers are belt feeders, which deliver the necessary quantity of material into a weighing hopper for weights up to 5 tons. This hopper has a mechanized closure, but when this is opened the material passes down a chute directly into the converter.

After the solid materials . . . 4.5 pct ore, 8 to 9 pct lime, and 0.8 to 1.0 pct bauxite . . . have been charged, and the hot metal has been poured into the converter, it is raised into the vertical position. The lance is then lowered into the mouth of the vessel at a rate of 10 to 20 in. per sec. At the same time, oxygen is turned on, with consumption being about 2120-cu-ft per ton of steel. The supply line pressure is 8 to 12 atm. Water for cooling the lance is delivered at a pressure of 7 atm and at the rate of 12,500 to 15,500 gal per hr. Close to the converter on the oxygen delivery line, two valves are installed: one cut-off and one control valve.

Waste gas treatment

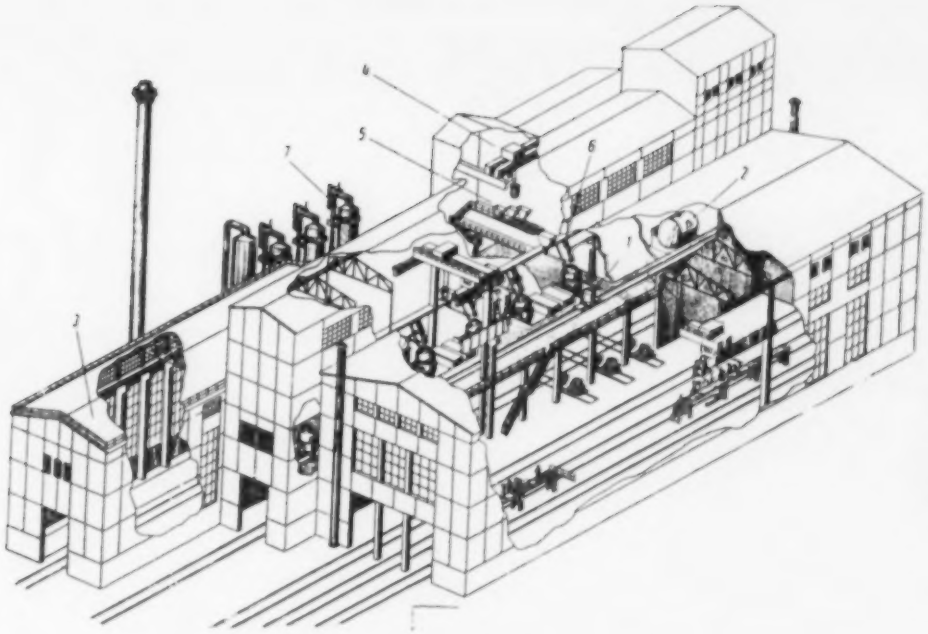
At a distance of 20 in. from the mouth of the converter is a water-cooled, waste-gas cooling element, about 9 ft in diam and 24 ft long, for the removal of the liberated gases. This hood can be withdrawn from the mouth of the converter by means of a special mechanism. The consumption of water in the cooling element is between 62,000 and 87,000 gal per hr at a pressure of 3 atm. The internal diameter of the gas extraction pipe is about 12 ft. At its top end, the gases are diverted into the cooling section of the stack, where sprayed water cools them to between 80° and 100°C. Then they pass into a 16.5-ft diam, 65-ft high scrubber without baffles. Next they enter venturi tubes with a drop in pressure equal to a 16-ft water column and pass into a cyclone of about 12 ft diam.

After a cleaning, the gases are discharged by a flue-gas exhaust fan into a stack just over 200 ft high. The dust content is about 0.057 grains per cu ft whereas their initial contamination with dust is about 24 g per cu ft. The output of the flue-gas exhauster is 2,648,000-cu-ft per hr, the pull being equivalent to 47 in. of water column. The capacity of the motor is 500 kva. The temperature of the gases in the flue-gas exhauster is 35°C. Each converter is equipped with a gas-cleaning plant.

Melting and casting

Charging of each converter is completely mechanized, while tilting the converter, lowering and raising the lance, and also the operation of the gas-cleaning plant are inter-locked, and controlled by an operator. The whole system of interlock and regulation of the delivery of oxygen and water is equipped with a control and measuring device, which not only indicates, but also signals any reduction in the quality of the oxygen and loss of water pressure. On one of the converters the installation of a waste-heat boiler and an electro-static gas-cleaning plant is planned.

In the casting bay there are three railway tracks; on two of these are located four casting platforms



The top-blown oxygen steel plant at Krivoi Rog. Numbers refer to the following: 1, hot-metal transfer ladle; 2, mixer; 3 solid materials stockyard; 4, 5-ton bridge crane; 5, bins for ore, bauxite, and limestone; 6, water-cooled gas-cooling element; and 7, scrubber without baffles.

with stands for casting the metal. The bay is equipped with four casting cranes of 75-ton capacity.

Metal from the converter is poured into a steel-casting ladle, seated on an electrically driven car, the movement of the car being controlled from a pulpit located under the working platform. The casting cranes deliver the ladles of metal to the casting stands, and by means of a shunting engine, the ingot mold cars are placed below the ladle. Slag from the converters is tapped into 388-cu-ft ladles. The slag ladle car is connected by an automatic link with the steel ladle car. Ladles filled with slag pass into the slag section, which is located in the vicinity of the main body of the converter building.

Steelmaking technique

Hot metal of the following composition is used for blowing: 0.5 to 0.8 pct Si, 1.0 to 1.4 pct Mn, max 0.055 pct S, and max 0.12 pct P.

After the hot metal is poured into it, the converter is placed in the vertical position, ore and limestone being charged along inclined chutes. The quantity of ore is determined from a calculation aimed at a final metal temperature of not more than 1630°C. The quantity of ore and limestone is found from the data given in Table I. For every 220 lb of ore charged, it is necessary to add a further 110 lb of limestone above the indicated quantity for slagging the silicon in the ore.

The metal is blown through a lance with a nozzle of 2½ in. diam. The oxygen consumption amounts to between 4250 and 4700-cu-ft per min, the pressure being 6 to 8 atm.

Table I. Converter Additions at Krivoi Rog

Si content of hot metal, pct	0.4	0.5	0.6	0.7	0.8	0.9
Quantity of ore, lb	3400	3700	4000	4300	4600	5000
Quantity of limestone, lb	4000	4300	4500	5000	5200	5400

During the production of low-carbon rimming steel, the melt may be conducted without intermediate tapping of the slag. But in the production of killed steels, after a blow of 7 min, the slag is tapped, and limestone is added for the second time. After this, the blow is continued until the necessary carbon content is reached.

In the converter shop at Krivoi Rog steelworks carbon steels are produced with an average nitrogen content of 0.006 pct.

Miscellaneous operations

At the end of the converter section are located special stands for knocking out converter linings, for fitting new ones, and for drying. The delivery of brick and mortar is mechanized, while drying is artifical. The converter vessel is transferred to the stand for repairs and back again by a bridge crane of 150 ton capacity. This organization of refits at a point remote from the converters in operation made it possible to increase the output of the shop by about 25 pct, and create favorable conditions both for the work of refitting and for the operation of the converters.

In the casting bay there are installed two compartment kilns for drying the stoppers, and stands for fitting pouring nozzles and stoppers to the ladles. The kilns and stands are served by two 2.5-ton cantilever cranes.

On completion of casting and after a certain holding period, the cars with the ingots are moved from the casting bay into the ingot stripping section, equipped with two bridge-type stripper cranes of 25 ton capacity and a knock-out ram exerting a pressure up to 175 tons.

Ingot molds are cleaned with water from jet sprays, two molds at a time, at a pressure of 70 atm, and transferred into the section where a stationary machine for mold coating is installed. The ingot-mold yard, equipped with four cranes of 20-ton capacity, has four platforms for preparing the cars, and also has three rail tracks.

DUST REMOVAL IN OXYGEN STEELMAKING

This is a survey of techniques used for the removal of dust from the brown smoke produced by the LD, basic oxygen steelmaking process. Translated into American, this article has been abstracted from a report of a meeting of the Eisenhütte Österreich, which was published in the November 1959 issue of Stahl und Eisen.

After substantial research and development work extending over a period of years, it appears that a feasible and economic solution to the problem of controlling brown fume produced by the LD, basic oxygen steelmaking process has been found. The economic aspect should be emphasized, since it is only by making use of both the waste heat contained in such gas, as well as the recovered particles themselves, than an economic solution to this problem was reached for European works.

The extraordinary fineness of the particles in brown fume—80 pct less than 0.8 μ, and the remainder 0.1 to 0.3 μ, with a substantial portion of millimicron size—and the high exit gas temperature —1700° to 1800°C—present difficulties in fume control which fully justified the research efforts herein described.

Table I lists LD steel plants presently in operation and under construction, along with the type of dust collectors installed at each.

Donawitz

At Donawitz, eight different dust collection systems were tried in a series of 509 different experiments, and the electrostatic method was found to be the best of the dry methods. Results are summarized in Table II.

It was first established that any method must use exit gas that had been cooled from 1800°C down to 300°-350°C, which would provide heat, in an average sized system, at the rate of 17 million kcal per hr to a waste heat boiler. It was found, however, that with only one LD converter in service, a surge in steam production took place during blowing, so an accumulator had to be installed in the system.

Total power consumption per metric ton of oxygen steel, including power for the oxygen plant, cranes, etc., was found to be about 150,000 kcal. Heat realized from the waste heat boiler amounted to 230,000 kcal per ton, which left a balance of 80,000 kcal which could be used for auxiliary power generation.

Even though the installation at Donawitz was a pioneer, with correspondingly higher costs of construction, it was found that credits for power, steam, and reclaimed dust, and 10 pct amortization per year actually produced a small income from the dust collection system.

As shown in Table II, the Lurgi electrostatic precipitator produced the cleanest gas in the experiments run at Donawitz; Fig. 1 illustrates this installation.

In planning this installation, it was first necessary to find the best method of cooling the gas to 150°C, the highest allowable temperature of gas entering this precipitator. As shown in Table III, there are three possible methods of doing this, and the most efficient, from an economic point of view, uses the least volume of water for cooling a given volume of gas. As can be seen, the waste heat boiler is most efficient.

As the boiler cools the fume only to 350°C, an evaporator-cooler is needed to make the final drop to 150°C. Control is achieved by regulating the amount of spray water according to the temperature of incoming gas, computed on the basis of complete evaporation of the spray water.

At present, the fine iron oxide powder collected in the precipitator, which amounts to ½ metric ton per hr, is collected in paper bags which are charged into the converter before the hot metal. This is done to avoid building up a circulating load of fines.

(*Continued on page 557*)

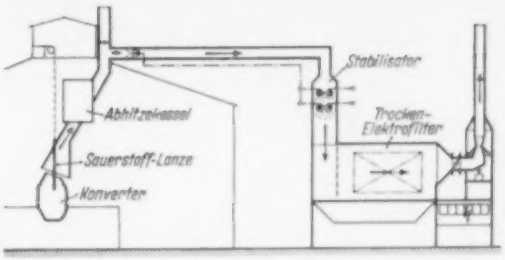
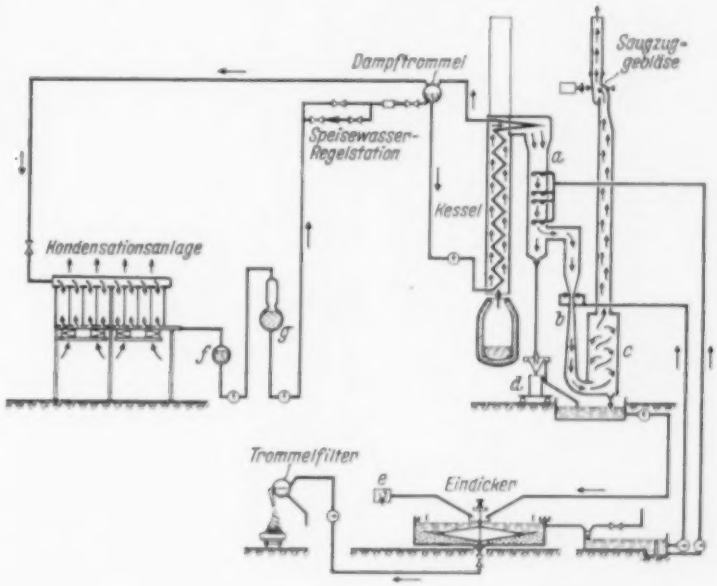
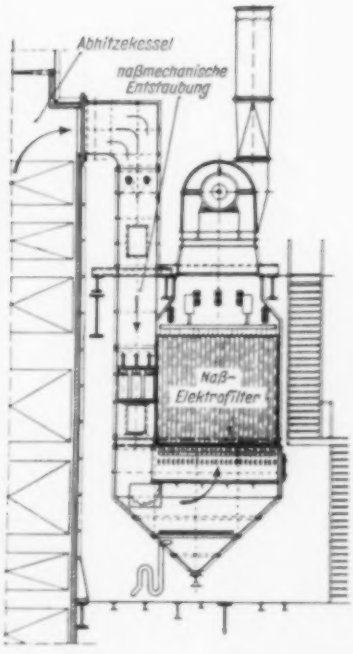


Fig. 1—(above) Dust removal unit at Osterreichisch-Alpine Montangesellschaft, Donawitz, Austria. Fig. 2—Bochumer Verein's dust removal unit, waste-heat boiler and slime treatment plant at Bochum, Germany. Letter indications are as follows: a, saturator; b, venturi; c, separator; d, pre-separator; e, lime-milk agitator; f, condensate tank; g, feed-water tank. From Stahl und Eisen, no. 23, 1959.





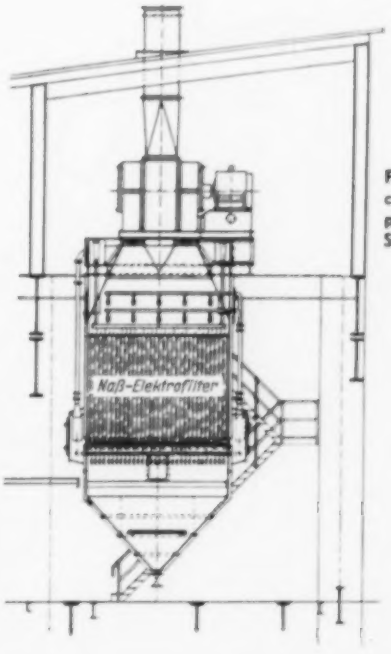


Fig. 3—Wet electrostatic precipitator installed at the VOEST plant in Linz, Austria. From Stahl und Eisen, no. 23, 1959.

Table I. Dust Separation in LD Steel Plants

	Name and Location	No./Capacity of Converters	Type of Dust Separation
1.	VOEST, Linz, Austria	3/30 ton	Converter 1: wet separation with waste heat boiler, Type Waagner-Biro (VOEST) Converter 2: wet separation with electrical fine cleaning, waste heat boiler, Type as above Converter 3: same as 2
2.	VOEST, Linz, Austria	2/50 ton	Wet separation with waste heat boiler, Type Waagner-Biro (VOEST)
3.	Österreichisch-Alpine Montangesellschaft, Donawitz, Austria	2/30 ton	Dry electrofilter, Type Lurgi with waste heat boiler, Type Waagner-Biro (VOEST)
4.	Companía Siderurgica Belga Mineira, Brasil	2/30 ton	Stack with graphite lining, no dust separation
5.	Dominion Foundries and Steel Ltd., Hamilton, Ont., Canada	2/35 ton 1/60 ton	Pease-Anthony-Venturi scrubber with partially cooled integral refractory stack Pease-Anthony-Venturi scrubber
6.	Algoma Steel Corp., Sault Ste. Marie, Ont., Canada	2/60 ton	
7.	Vuoksenniska, Finnland	2/15 ton	No dust separation
8.	Société des Aciéries de Pompey, Pompey, France	2/15 ton	Pease-Anthony-Venturi scrubber with waste heat boiler, Type Waagner-Biro (VOEST)
9.	Bochumer Verein für Gussstahlfabrication AG, Bochum, Germany	2/35 ton	Wet separation with electrical fine cleaning, waste heat boiler, Type Waagner-Biro (VOEST)
10.	Gusstahlwerk Witten AG, Witten, Germany	1/20 ton	Water cooled stack, Type Waagner-Biro; no dust separation
11.	Hindustan Steel Co., Rourkela, India	3/40 ton	Pease-Anthony-Venturi scrubber with waste heat boiler, Type Waagner-Biro (VOEST)
12.	Nippon Kokan Kabushiki Kaisha, Kawasaki, Japan	2/50 ton	Electrofilter, Type Lurgi with waste heat boiler, Type Waagner-Biro (VOEST)
13.	Nippon Kokan Kabushiki Kaisha, Kawasaki, Japan	2/70 ton	Wet separation with electrical fine cleaning, waste heat boiler, Type Waagner-Biro (VOEST)
14.	Yawata Iron & Steel Co., Tobata, Japan	2/50 ton	Wet separation with electrical fine cleaning, waste heat boiler, Type Waagner-Biro (VOEST)
15.	Yawata Iron & Steel Co., Yawata, Japan	2/50 ton	Pease-Anthony-Venturi scrubber with partially cooled refractory stack
16.	Kon. Nederl. Hoogovens en Staalfabrieken, Ijmuiden, Netherlands	2/70 ton	
17.	Siderurgica Nacional SA., Lisboa, Portugal	2/20 ton	
18.	SICI, Barcelona, Spain	1/5 ton	
19.	Altos Hornos de Vizcaya, Bilboa, Spain	2/36 ton	Pease-Anthony-Venturi scrubber with water cooled stack, Type Waagner-Biro (VOEST)
20.	Kaiser Steel Corp., Fontana, Calif.	3/60 ton	Dry electrofilter
21.	Jones & Laughlin Steel Corp., Aliquippa, Pa.	2/60 ton	Dry electrofilter
22.	Jones & Laughlin Steel Corp., Aliquippa, Pa.	1/60 ton	Dry electrofilter
23.	McLouth Steel Corp., Detroit, Mich.	3/30 ton	Wet precipitation with disintegrators
24.	McLouth Steel Corp., Detroit, Mich.	2/70 ton	Wet separation with disintegrators

Table II. Preliminary Experiments in Donawitz

System	No. of Experiments	Flue Gas, cu m	Avg Dust Content per N. cu m
Theisen, small washer	90	2000 to 4000	150 mg
Theisen, big washer	5	30,000	360 mg
Pease-Anthony washer	35	2,200	588 mg
Flashed water	125	143	313 to 3400 mg
Coke filter	26	1900 to 2100	unsatisfactory
Slag wool	18	1,200	unsatisfactory
"Bierhauer" magnetic filter	72	1,800	unsatisfactory
Electromagnetic filter	62	750	unsatisfactory
Lurgi dry electrofilter	75	3600 to 5700	96 mg
	509		

Table III. Flue Gas Amounts, Water Consumption, and Required Cleaning From a 30-Ton Oxygen Converter With Different Methods of Gas Cooling

Method of Pre-cooling	Amount of Gas, N cu m/min	cu m (150°C)/min (After Evaporation Cooling)	Water Consumption, kg/charge	Dust Content, g/cu m (op. temp)	Required pct Cleaning for 100 mg/cu m (op. temp)	Size of Electrofilter
a) Waste heat boiler, to 350°C n = 2	683	1188	1350	18.4	99.46	1
b) Water cooled stack, to 700°C n = 4	1289	2810	7080	7.8	98.72	1.98
c) Increased excess air, to 700°C n = 6	1895	4130	10,400	5.3	98.11	2.64

Assumed: 30 ton crude steel with 4 pct C, Blowing time: 20 min.
Dust content leaving converter: 350 kg/charge. n = excess air.

Table IV. Operating Results of the Dry Lurgi-Electrofilter in Donawitz

Oxygen converter for 33 ton crude steel; Blowing time: 20 min;
Flue gas: approx 50,000 N cu m/h
Dust load: 350 kg/charge = 1.09 pct based on tons of steel production

Dust content in gas:

Entering electrofilter	11.7 g/cu m (op. temp)
Leaving stack	0.014 g/cu m (op. temp)
Stack discharge	0.407 kg/charge
Efficiency of collection	99.88 pct

Power consumption

	kwh/t steel	kwh/1000 N cu m, dry
Electrofilter	0.23	0.40
Complete installation (incl. fans)	0.62	1.20
Water consumption: approx 1500 kg/charge		

It should be noted that the powder is also useful as a scavenger in gas desulfurization operations, and interest has been shown by the dye and ceramic industries for other possible uses.

Based on present conditions, overall operating statistics for gas cleaning are given in Table IV. The precipitator shows almost no draft loss, and the fan power is low, amounting to only 0.39 kw-hr per metric ton of steel.

Bochumer Verein

The new plant of Bochumer Verein in Höntrop includes two 35-ton LD vessels and a 70-ton electric furnace. A stack 8.4 m wide and 39 m high provides exhaust for this shop.

The dust cleaning equipment was patterned after that found in the DOFASCO and McLouth plants in Canada and the US. In both locations, wet cleaning is practiced, Dominion using a Pease-Anthony venturi washer and McLouth a disintegrator. Each of these systems uses a great quantity of water which is discharged into the lake. At Höntrop, only the saturator, venturi nozzle, and separator from the Pease-Anthony unit were adopted, so as not to overload existing water-treatment facilities.

A 520-kw fan producing a 1200-mm wg vacuum sucks the effluent gases from the converter and through a waste-heat boiler and a wet cleaner. Steam from the boiler is not used at present, since production is discontinuous and there is no steam consumption at Höntrope. A condenser is employed, and the water is pumped back into the boiler. The condenser will eventually become part of a power plant. Gas enters the saturator at 700° to 900°C, depending on whether scrap or ore is used for cooling in the heat; the gas is cooled to 80°C and fed into the venturi nozzle.

The gas flows through the venturi nozzle with a velocity of 100 m per sec at the smallest cross section, where high-pressure water is sprayed in through a jet carburator at right angles to the flow. The cleaned gas leaves the stack at approx 70°C, and carries only 150 mg of dust per cu m. Water consumption is 0.2 cu m per metric ton of crude steel.

Particles in the flue gas as it leaves the converter are 90 pct −0.6 mm. The larger fraction, made up mostly of particles of slag and fluxing additives, is caught in the saturator, along with some smaller particles. The remainder of the particles are scrubbed out in the venturi unit.

The water treatment plant was developed after extensive experiments and is shown in Fig. 2. Sludge from the saturator is mixed with the dust-laden water from the venturi, as the former carries most of the coarse particles which are necessary for proper filter operation. All of the water first goes to settling tanks where milk of lime is added. The thickened mud is then filtered in cell-less trumpet filter. The filter cake contains approx 30 pct moisture, and on a dry basis 50 pct iron and 10 pct lime. All recovered dust and the filter cake are recycled directly to the blast-furnace ore bunker, without sintering.

In a 35-ton heat, about 800 kg of thick mud is produced, which corresponds to 560 kg dry dust, and this contains 280 kg of iron, which amounts to 8 pct of the charge. Sludge entering the settling tank carries 6 to 10 kg of solids per cu m of water, while liquid flowing out contains only 0.3 to 0.8 kg per cu m. This is decreased by further settling in the pump sump to 0.1 to 0.2 kg per cu m. Filtrate from the suction filter contains only 0.05 kg per cu m of water.

Dust separation costs are very high at this plant, as steam consumption is negligible. However, with the erection of a power plant, it is expected that the dust separation operations will at least break even and should show a small profit. Experience with the present system to date has fully proved the reliability of this process.

Linz and Ijmuiden

The first dust collecting system installed at Linz, Austria, included a waste heat boiler, but gave only 36 pct collecting efficiency. This was improved by admitting the exit gas through slotted rings into *turbulence pipes* where water entered through spray rings. From here, the gas was sucked into cyclones, and efficiency of the system jumped to 96.4 pct. Draft loss of the system was 550 mm wg. Dust separation was calculated as 1.28 g per cu m. Later, a wet electrostatic precipitator shown in Fig. 3 was installed to replace the cyclones, and it achieved an efficiency of 99.7 pct. This unit processed 13,300 cu m of gas per charge, and from gas containing 350 kg of dust per converter charge only 1.1 kg of dust was ejected from the stack.

With regard to the waste heat boiler installation, several years experience has shown that the new type of high-pressure boilers generally are not any more sensitive to this type of service than the conventional low-pressure units. To avoid slag accumulation on the boiler surfaces, it is necessary to provide at least 7 to 8 m distance between the converter outlet and slag screen. Through the choice of suitable soot-blowers, the boiler cleaning problem can be solved. In more than 20,000 hr of service, a high-pressure unit with 71 kg per sq cm pressure and 530°C operating temperature gave a perfectly reliable load and service record.

At the Ijmuiden plant in the Netherlands, which presently has two 70-ton converters and operates on a 25 min blowing cycle, a total of 126,000 (normal) cu m of waste gas is produced per hr; this corresponds to 300,000 cu m at exit temperature. This gas is thoroughly cleaned by a Pease-Anthony venturi scrubber so as not to harm the adjoining flower fields. Water consumption is 25 cu m per charge or 350 kg per metric ton of iron in the charge, and the gas leaving the stack contains only 110 mg of dust per cu m.

Recovery of iron values through treatment of the waste water at Ijmuiden amounts to 1.8 pct Fe_2O_3 and approx 3 pct CaO, based on charge weight. Filter cake collected at the filter outlet is mixed with approx 10 pct CaO, yielding a partly pelletized material that is particularly well suited to sintering. Over 800 tons of this material is sent each month to the sinter plant.

Conclusions

The problem of waste heat recovery and dust removal from the Kaldo and the Rotor basic oxygen steelmaking processes is much less important than for the LD process, because of the relatively greater amount of coarse dust particles. This makes possible the utlization of conventional dry precipitation methods. Nevertheless, the installations discussed in this article have provided an efficient and economic treatment of brown fume from the LD process.

METALLURGICAL CHARACTERISTICS OF THE KALDO PROCESS

This paper discusses the metallurgy of the Kaldo process as normally applied to high-phosphorous hot-metal operations at Domnarvet. In addition, experience in the treatment of other types of hot metal is discussed in some detail with much new information brought to light on this aspect of the process.

by Bo Kalling, Folke Johansson, and Erik Bengtsson

The Kaldo process[1-4] has been in commercial use at Domnarvet, Sweden, since 1956, and more than 300,000 tons of ingots have been produced. Phosphorous-rich hot metal has been successfully refined in a 30-ton furnace, and the operating practice is now well-established for this kind of pig iron. In addition, quite a number of heats have been made from medium- and low-phosphorous hot metal. As most of the carbon monoxide developed in the bath is burnt to carbon dioxide inside the rotating vessel, the heat economy is excellent and large amounts of scrap or iron ore can be melted. Continuous feeding of ore, which will be used in the future, gives a more uniform reaction and improves the heat economy. Due to rotation, process control is very accurate, and chemical analysis and tapping temperature can be kept within close limits. Iron losses in slag and fumes are low. The local metal temperature in the Kaldo process at the spot where primary reactions between oxygen and iron take place is comparatively low, and the main part of the dust is of 3 to 20 μ size. Nitrogen pick-up is extremely small, even with oxygen of 95 pct purity. Desulfurization is very effective, and by lowering the rotation speed of the furnace, the iron content of the slag can be increased in order to accelerate dephosphorization, which is especially important when refining phosphorous-rich iron to a high-carbon steel with low-phosphorous content.

High-phosphorous hot metal

In Domnarvet, an ordinary basic-bessemer hot metal of the following analysis is normally used: 3.1 to 3.7 pct C, 0.2 to 0.4 pct Si, 0.6 to 0.9 pct Mn, 1.7 to 2.0 pct P, and 0.035 to 0.80 pct S. The furnace is charged with 28 to 33 metric tons of pig iron, and slag formers and cooling agents are then added in the form of fine lime (100 to 130 kg per ton pig iron) and ore (120 to 150 kg per ton pig iron) after which the blowing is started. The course of a heat is shown in Fig. 1 where the change in the analysis of the metal bath is shown as a function of oxygen consumption. Interruptions in the refining must be made in order to take bomb samples before a liquid slag is formed. The diagram also shows the exhaust-gas temperature measured at a certain location in the exhaust main. After each interruption for sampling, there is a short lag before the temperature resumed its original level.

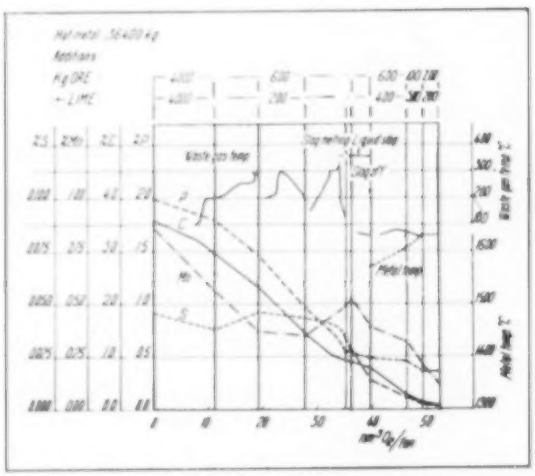
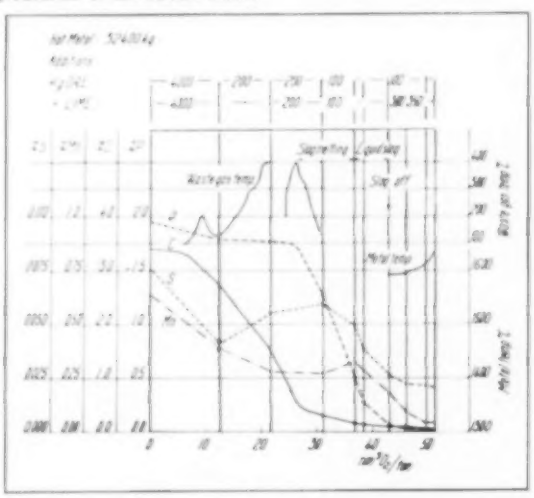


Fig. 1—Typical Domnarvet heat with early dephosphorization.

Fig. 2—Heat with late dephosphorization—satisfactory for the production of low-carbon steels.



BO KALLING, FOLKE JOHANSSON, and ERIK BENGTSSON are associated with Stora Kopparbergs Bergslags A/B at Domnarvet, Sweden. This paper was presented at the 1960 AIME Annual Meeting.

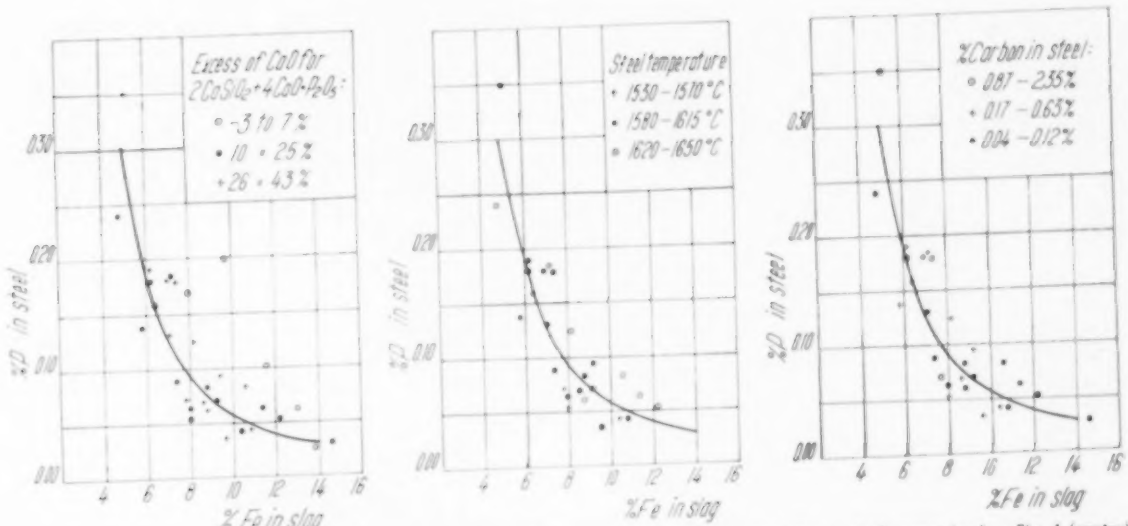


Fig. 3 (left)—Iron content of first slag when refining hot metal with 1.85 pct P; grouped according to CaO excess in slag. Fig. 4 (center) —Same, grouped according to steel temperature. Fig. 5 (right)—Same, grouped according to carbon content of steel.

First blow: During the first blowing minutes, the silicon and a considerable part of the manganese of the hot metal is oxidized, while carbon and phosphorus oxidation proceeds relatively slowly. The exhaust-gas temperature during this period is about 100°C at the measuring point. When the main portion of the silicon has been oxidized, the carbon boil starts, and the exhaust temperature increases rapidly on account of the increased gas volume. During the carbon refining, there is a simultaneous phosphorus oxidation. With a relatively high-silicon content in the hot metal, and consequently more slag, the boil is quiet and the measured exhaust-gas temperature under 300°C. When using hot metal with low silicon content and charging ore at the beginning, there is a more violent and more spontaneous boiling reaction. By decreasing the rotational speed of the furnace and blowing the oxygen at a flatter angle towards the bath, it is possible to moderate the boiling reaction to a great extent. A moderate boil with a low and even exhaust-gas temperature is desirable, because it gives a considerably higher heat yield through a more complete combustion of carbon monoxide to carbon dioxide inside the furnace. When using scrap for cooling, a uniform boiling reaction is generally obtained with low exhaust-gas temperatures.

It is interesting to note, that considerable dephosphorization occurs during the entire boil, although the slag melts only towards the end. The quieter the boil, the greater is the extent of this dephosphorization.

Additional manganese is oxidized during the first part of the carbon oxidation, but the manganese content then remains constant when the carbon reaction reaches its maximum.

With higher temperature in the heat, the reactivity of the lime increases, and the speed of dephosphorization increases during the final phase of the boil; this is characterized by a noticeable decrease in the exhaust-gas temperature. During this period, the slag begins to melt and more and more of the lime is used for slag formation. This change from an unmelted to a liquid slag also makes itself known through an increase in the load on the driving motors for the furnace rotation, probably because the half-melted slag has a tendency to stick to the furnace wall and be lifted up by it. With the complete melting of the slag, there is a very rapid decrease of 40 to 50 pct in the motor load to a value characteristic of liquid slag. This usually occurs at a phosphorous content of about 0.5 pct. Up to this point, there is a noticeable reversion of manganese, which is a well-known phenomenon also in the basic-bessemer process. This reaction of manganese reaches maximum at a low iron content of the slag. After this characteristic phase, the dephosphorization is usually completed after further injection of 7 to 8 N cu m O_2 per ton of hot metal. After all the slag has melted, the manganese again begins to oxidize simultaneously with the phosphorus.

The main desulfurization takes place during slag melting and particularly after a liquid slag has been obtained. It is true, that the lime removes some sulfur at an early stage, but during the carbon boil, the sulfur reverts to the steel. This sulfur removal by the lime at the beginning of the blow, which occurs also in the basic bessemer process, is more noticeable in a heat of the type shown in Fig. 2. In this heat, the boil has been more intensive, and no appreciable dephosphorization took place before the carbon content had decreased to about 0.5 pct. This is entirely sufficient for production of steels with low-carbon content.

A late dephosphorization is to be preferred in view of the lining attack. It has become evident that the lining attack, even with very good carbon monoxide combustion, is very slight as long as there is no liquid slag, but it increases rapidly towards the end of the cycle, as the iron content in the slag increases. By determining the MgO content in the slags, it has been found that the lining attack from the beginning of the blow up to the first slag-off is only about 8 kg of dolomite per ton. In spite of the fact that the final dephosphorization period is only 15 to 20 pct of the total time and during this period only 5 to 10 pct of the carbon is removed, the lining attack during this period is of the same order of magnitude as during the long period up to the first slag-off.

First slag: The first slag-off usually takes place at a phosphorous content of about 0.100 pct. The cor-

responding carbon content can be varied within wide limits but is usually 0.10 to 0.30 pct C when low-carbon steels are being produced. If it is desired to remove the phosphorus at a higher carbon content, the ore addition is decreased so that the temperature required for slag melting is reached earlier. Sometimes the slag is tapped off at higher carbon contents in order to achieve an especially good desulfurization. The manganese content at the first slag-off varies with the phosphorus content, but it is usually about 0.2 to 0.3 pct.

The first phosphate slag amounts to about 220 kg per ton of pig iron and contains 6 to 10 pct Fe. An average of 80 pct of this slag is tapped off. The temperature at the first slag-off is usually 1580° to 1610°C.

Final blow: After charging an additional 10 to 15 kg lime per ton of pig iron and up to 10 kg ore, the steel is refined to the desired carbon and phosphorus contents at a suitable tapping temperature of 1620° to 1650°C.

The weight of the second slag is usually about 80 to 100 kg per ton of pig iron with an iron content of 15 to 20 pct. The tapped off portion of this slag varies between 40 and 70 pct of the total.

When producing steels with a maximum content of 0.02 pct P in the finished steel there is usually one additional slag-off, primarily in order to improve the steel yield and prevent reversion of the phosphorus during tapping. An additional 4 to 7 kg of lime is then added. If such a third slag is formed, the iron content in this slag will increase to 20 to 28 pct, and the quantity usually is 50 to 70 kg per ton of hot metal.

Only part of the final slag is tapped off, the balance being retained in the furnace during tapping by adding about 20 kg of lime per ton for stiffening. This lime and the retained slag is used during the subsequent heat.

High-Carbon steel: When making high-carbon steels, the first slag is removed at a carbon content of 1.0 to 1.5 pct C, depending on the desired final carbon content. The iron content in the slag controls the phosphorus content in the bath, which varies between 0.2 and 0.3 pct. In order to bring the phosphorous content down to low values, about 10 to 15 kg of lime per ton and about 10 to 15 kg of ore per ton are added after the slag-off, and the rotational speed of the furnace is adjusted during the continued refinement so that no appreciable boiling reaction is created. In this way, an oxidizing slag is formed with the ability to remove the major portion of the phosphorus remaining in the bath. The carbon oxidation does not start again until the phosphorous content in the steel has been brought down to a low value.

The carbon content is then brought down to the desired value, which can be done successfully and with great accuracy under a very basic slag with controlled iron oxide content.

Slags: The slag obtained in the Kaldo process at the first slag-off is a phosphate slag of the same type as in the basic-bessemer process. The normal composition is 18 to 20 pct P_2O_5, 7 to 8 pct SiO_2, 51 to 54 pct CaO, 2.5 to 3.5 pct MgO, 2.5 to 3.5 pct MnO, and 5 to 10 pct Fe.

The properties of this type of slag, which influence the phosphorus content of the liquid steel, and which are well known for the basic bessemer process, are the content of iron oxide, the basicity, and the temperature. Fig. 3 shows the relation between the phosphorus content of the steel and the iron content of the slag. The extraordinarily strong influence of the iron content of the slag on the phosphorus content of the steel at the first slag-off is quite evident.

The same diagram also shows the importance of a slight excess of lime in the slag in order to make sure of a complete dephosphorization. If the relation between the actual CaO content of the slag and what is theoretically required in order to bind silicon and phosphorus as 2 $CaO \cdot SiO_2$ and 4 $CaO \cdot P_2O_5$ respectively is less than 1.10, the dephosphorization is found to be considerably impaired. On the other hand, the diagram shows that a lime surplus of more than 10 pct does not appreciably improve the dephosphorization and does not influence the illustrated relationship.

In Fig. 4, slags with an insufficient amount of excess lime have been excluded. Furthermore, the slags have been grouped according to steel temperatures. The known tendency of dephosphorization to decrease with increasing temperature is confirmed. Fig. 5 shows that, on the other hand, the carbon content has no influence on the relation between the phosphorus content of the steel and the iron content of the slag.

With the large excess of lime required to bind the phosphorus effectively in the final slag when the phosphorus content of the steel has been brought down to values under 0.020 pct P, the iron content of this slag will be very high, especially at low silica contents. (Fig. 6). A silica content of 4 to 6 pct has proved to be optimum, if both the P_2O_5:P ratio and the iron content of the slag are taken into consideration.

The main part of the desulfurization takes place before the first slag-off. Of the factors which influence desulfurization during this part of the process, the lime basicity is evident. In Fig. 7 the influence of the slag content of iron is demonstrated. A low iron in this slag seems to give better sulfur removal in accordance with the reaction $CaO + FeS = CaS + FeO$. The diagram also shows some favorable influence of the carbon content on the desulfurization. The normal sulfur removal when refining basic-bessemer iron is 65 to 80 pct. Slagging-off at a high carbon content when the iron content in the slag is relatively low gives particularly good sulfur removal, and this is utilized when very low sulfur content is desired.

Low-phosphorous hot metal

Refining pig iron with 0.1 to 0.3 pct P is considerably easier than refining pig iron with higher phosphorus content. The reason for this is partly due to the lower slag volume, and partly due to the lower P_2O_5 content of the slag which makes it easier to come down to low phosphorus contents even at high carbon contents.

With scrap cooling or continuous ore changing, it is possible, at normal silicon contents, to refine the steel directly to the desired carbon content without any extra slag tappings, but is advisable to interrupt the blow for temperature control and carbon check while the carbon still is 0.2 to 0.3 pct above the value desired before tapping. In this way, closer temperature and analysis limits can be maintained in the finished steel. In connection with this stop for sampling, it is at the same time also convenient to tap off the main part of the slag, since it will

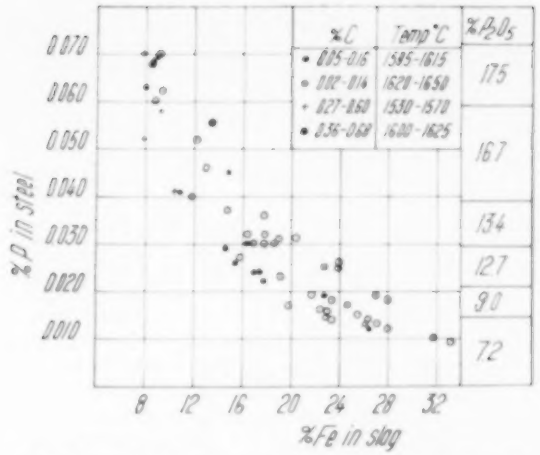


Fig. 6—Iron and P_2O_5 content of the slag with decreasing phosphorus content in the steel when using hot metal with 1.85 pct P.

Table I. Example of Desiliconizing in the Kaldo Furnace

Charged: 25,700 kg hot metal
500 kg lime
165 kg sinter (cold furnace).
Blowing: 440 N cu m O_2 for 9 min
Extra rotation without any O_2 for 1 min

Metal analysis, pct	C	Si	Mn	P	S	°C
Before blowing	4.08	0.91	1.08	0.160	0.041	1190
After blowing	3.76	0.00	0.7	0.194	0.023	1480

Slag analysis, pct	CaO	MgO	SiO_2	P_2O_5	MnO	FeO
After blowing	46.7	4.49	38.2	0.03	7.2	1.74

not take up any more phosphorus or sulfur during the continued blow. Furthermore, the iron content of the slag increases with decreasing carbon content, and the steel yield will be lower, if the entire slag volume is kept in the furnace until the heat is finished. This is especially true when producing steel with extra low carbon contents.

For ore cooling and silicon content in the pig iron over 0.5 pct, an improved refining technique has been developed. No more lime is charged before the start than what is required to bind the silica in the slag with a $CaO:SiO_2$ ratio of about 1.3. The ore addition is adjusted so that the metal temperature will be about 1500°C when the main part of the silicon has been oxidized but the carbon boil has not yet gained much speed. It has been proved that this slag, which in composition resembles a blast-furnace slag, can be reduced to a very low iron content. The major portion of the silicon content of the pig iron can, thus, be removed without any loss of iron.

Table I shows an example of such a pre-refining in which the iron content of the slag was reduced to 1.4 pct before slag-off. This example also shows that this pre-refining technique at the same time gives a very good desulfurization, in this case 44 pct. Fig. 8 shows a heat where this technique has been applied.

After the silica-rich slag has been removed, the refining is continued with only enough slag volume for the dephosphorization when simultaneously further desulfurization is obtained.

This pre-refining technique can also be used advantageously with scrap cooling as, in addition to an improved steel yield, it also gives a better heat economy.

The dephosphorization of hot metal with 0.2-0.3 pct P is shown in Fig. 9. The diagram shows that the

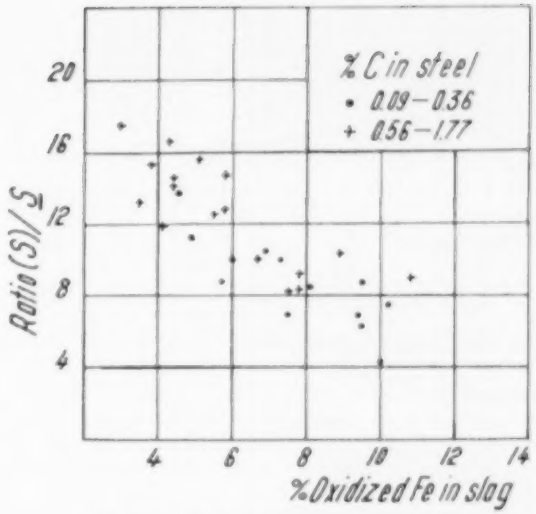


Fig. 7—Sulfur distribution in slag and steel at first slag-off when using hot metal with 1.85 pct P.

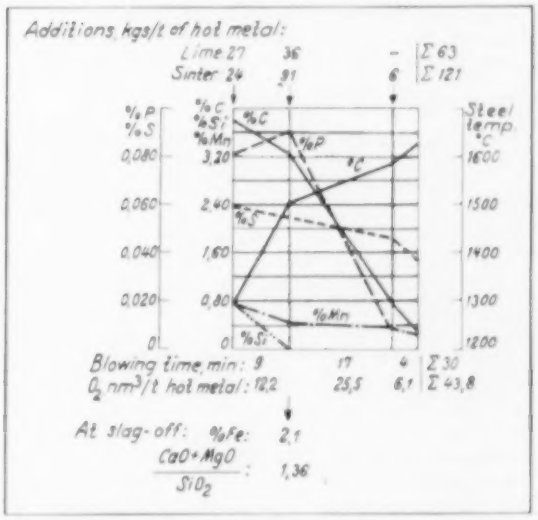


Fig. 8—Heat with slag tapped after removal of silicon. Hot metal analyzes: 3.82 pct C, 0.75 Si, 0.75 pct Mn, and 0.081 pct P. Resulting steel contains: 0.15 pct C, 0.67 pct Mn, 0.015 pct P, 0.028 pct S, and 0.002 pct N.

ratio between the P_2O_5-content of the slag and the P-content of the steel normally is higher at lower phosphorus content in the steel. Fig. 10 shows, furthermore, that a basicity, expressed as $CaO/(SiO_2 + P_2O_5)$, above 3.25 does not seem to give a higher P_2O_5-content in the slag than a basicity of 2.75 to 3.25.

The diagram in Fig. 11 is a repetition of the foregoing, but it has been arranged according to temperature and carbon content instead of basicity. A series of heats were made with over 1 pct C in the finished steel, and the diagram shows that the P_2O_5-content of the slag was practically the same at low and high carbon contents. No influence of the temperature could be observed. The number of tests, however, was too small to permit any definite conclusions.

As in the phosphorous-rich slags, the phosphorus content of the steel adjusts itself to the iron content of the slag, as is shown in Fig. 12. Also in this re-

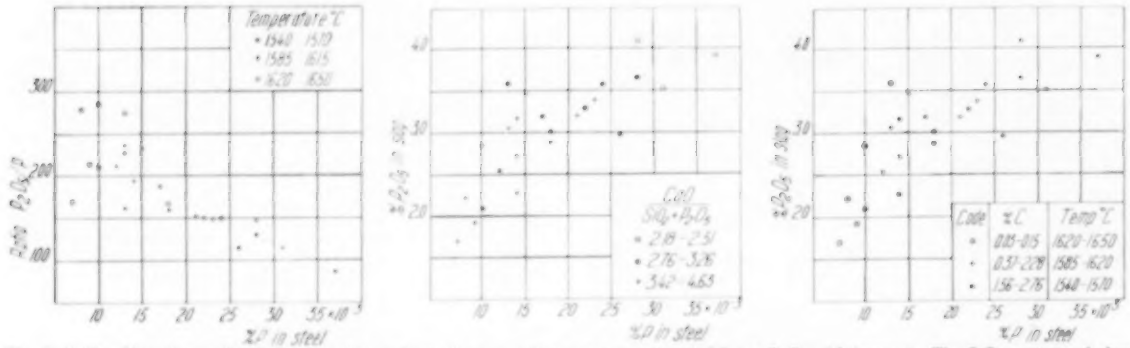


Fig. 9 (left)—Phosphorus distribution in slag and steel when refining hot metal with 0.2 pct P. Fig. 10 (center)—The P_2O_5 content of slag from same hot metal, grouped according to basicity. Fig. 11 (right)—Same, grouped according to carbon content and temperature.

spect, there is no appreciable difference between the groups with high and low carbon content. However, the highest iron content may have been influenced by the carbon content being only 0.03 in the steel. Lower temperature is accompanied by higher iron-content in the slag, presumably because a higher iron-oxide content is necessary to keep the slag from becoming too viscous.

The total sulphur removal depends on the slag volumes. Normal desulphurization by refining low-phosphorous metal is 50 pct.

Other types of hot metal

Besides the high-phosphorous, basic-bessemer hot metal used for the Kaldo process in Domnarvet, and the tests which have been made with low-phosphorous iron, a number of other iron types of varying composition have been used in other tests.

For instance, a number of heats have been made with the following medium-phosphorous iron: 3.95 to 4.00 pct C, 0.73 to 0.86 pct Si, 0.34 to 0.42 pct Mn, 0.014 to 0.040 pct S, and 0.64 to 0.68 pct P.

From this hot metal a number of heats were made, some with 0.70 pct C. Some of the heats were cooled with ore and some with scrap. With ore-cooling a pre-slag was tapped off in accordance with the technique developed for low-phosphorous iron. No appreciable phosphorus removal takes place in this pre-slag in which a low basicity is desired.

The phosphorous-rich slag was tapped off with about 0.1 pct P in the steel, when 0.1 to 0.2 pct C remained to be removed.The approximate slag composition was: 10 to 15 pct SiO_2, 8 to 11 pct P_2O_5, 50 to 55 pct CaO, 3 to 5 pct MgO, and 5 to 8 pct Fe_t. After a small addition of lime and ore, the steel was refined to the desired carbon and below 0.030 pct P, at the same time adjusting the steel temperature. The final slag contained: 6 to 9 pct SiO_2, 4 to 7 pct P_2O_5, 40 to 45 pct CaO, 4 to 5 pct MgO, and 15 to 20 pct Fe. A substantial part of this slag was retained for the next heat.

It is interesting to compare dephosphorization with this type of pig iron with the more silica-poor phosphorous slag which is obtained when refining basic-bessemer hot metal. From Fig. 13, which shows the relation between the iron content of the slag and the phosphorous content of the steel, it is evident that in this case (0.66 pct P hot metal), the iron content is lower, which seems to be related to the higher silica-content of this slag. In Fig. 14 the average values have been calculated for both slag types, including only slags taken at a steel temperature of 1620° to 1650°C. This diagram shows that the P_2O_5:P ratio is lower in the silica-rich slags. With an excessive silica-content it is, thus, necessary to have a larger slag volume in order to come down to the desired phosphorus content in the steel. When refining a high-phosphorous hot metal and cooling with ore or sinter, these additions should not contain too much silica. If, on the other hand, the silica-content in the slag is too low, its iron content will be unnecessarily high with resulting decrease in the steel yield.

Among the tested iron types, the following extreme analysis can be mentioned: 2.14 pct C, 3.2 pct Si, 0.21 pct Mn, 1.35 pct P, and 0.120 pct S.

Ore was used for cooling. Refining of such a pig iron is carried out in much the same way as for the earlier-described iron with 0.8 pct Si and 0.7 pct P. Because of the mixing obtained through rotation, it was easy to oxidize the large amount of silicon. After the silica slag of low basicity had been tapped off at about 0.2 pct Si in the steel, more lime and ore were added, and the carbon and phosphorus refining carried out in the usual manner.

From this hot metal ship plate and deep-drawing sheets were produced with a specification of 0.02 pct P max and 0.025 pct S max. In one of these heats a desulfurization from 0.164 to 0.018 pct was obtained, due to the good sulfur removal in both pre-slag and the phosphate slag.

Steel quality

The Domnarvet Kaldo steel has been used in a number of applications with especially high requirements for good cold working properties, impact strength, and non-aging characteristics.

Test ingots and rolled steel, delivered to a number of steel mills interested in the process, have been found satisfactory in comparative tests with other steels for a large number of applications. This is true, both for extremely low-carbon content steel, for instance, in electrical sheets, and for high-carbon tool steels. The reason for the good steel quality, in addition to the low contents of sulfur, phosphorus, and nitrogen, can be attributed to the capability of the process in carrying out the reactions in a way suitable for each type of steel and of controlling the course of the heat and the tapping temperature.

So far there is only little experience in the manufacture of alloy steels. The reason for this is that there are no alloy steels on the Domnarvet production program. Up to 1.5 pct Mn and 1 pct Cr have been added in the furnace and 1.5 pct Si in the ladle. From these heats it is, however, clearly demonstrated that the ferroalloys melt and dissolve uniformly in the steel faster than usual, due to the

stirring from rotation. With a gas or oil burner introduced through the mouth or by increasing the steel temperature before additions, it should be possible to increase the additions still more.

Good experience has been obtained with recarburization of steel and alloying with silicon when producing hematite pig-iron from basic-bessemer hot metal in the Kaldo furnace. For instance, recarburization was carried out with coke from 0.79 to 3.72 pct C in 11 min, while the temperature of the bath decreased from 1450° to 1350°C. The reason for the low temperature drop during this strongly endothermic reaction was that the reduction gas and part of the coke could be burned to carbon dioxide by the oxygen which was blown into the furnace during the recarburization. After another 6 min of rotation with a low flow of oxygen, 4 pct C was obtained, and the temperature increased to 1360°C. After the recarburization 75 pct FeSi was added in order to increase the silicon content by 3.5 pct. The silicon yield was 96 pct after 10 min rotation.

Acid operations

In Sweden, because acid open-hearth steel has proven to be superior to basic steel with the same analysis for certain applications, the Kaldo process has also been tried as an acid process. These tests have been made in a 3-ton furnace. Both ore and scrap have been used as the coolant. The process was extremely simple to regulate, and it was easy to control the temperature and obtain the slag composition which is desired in the acid open-hearth process. These tests showed that, in spite of complete combustion of the carbon monoxide, the lining attack was considerably less than with a basic lining. This confirms the theory that high temperature from the combustion of the carbon monoxide above the bath is not dangerous to the lining life. Due to the low lining cost for the acid process it is possible, with availability of low-phosphorous ores, to produce the acid steel at a lower cost than the basic steel. Furthermore, it may be possible to obtain a steel with less slag inclusions. Additional tests with acid lining are planned.

Conclusions

From the above description of the Kaldo process and its use for refining of different iron types, it is evident that the process is extremely flexible. This is true, not only with reference to the composition of the hot metal and the production program, but also in connection with the ability to adjust the process in accordance with the temporary price relations between iron and scrap. During the last few years, the scrap prices in some areas have fluctuated widely, and it is thus valuable to be able to base production either on pig iron with ore as a coolant or in other cases with as much scrap as possible. In the latter case more than 40 pct of the total metallic charge can consist of scrap, which is a very high proportion for a pneumatic process.

References

[1] Folke Johansson: Swedish Oxygen Steelmaking. JOURNAL OF METALS, vol. 9, July 1957, pp. 972-975.

[2] Bo Kalling and Folke Johansson: Refining Pig Iron with Oxygen According to the Kaldo Process. *Revue Universelle des Mines*, vol. 14, 1958, pp. 455-466.

[3] T. Olof Dormsjo and D. R. Berg: The Kaldo Oxygen Steelmaking Process, its metallurgy, and economics. *Iron and Steel Engineer*, vol. 36:4, April 1959, pp. 67-77.

[4] Bo Kalling and Folke Johansson: Further Experience with the Kaldo Process. *Journal of the Iron and Steel Institute*, vol. 192, August 1959, pp. 330-338.

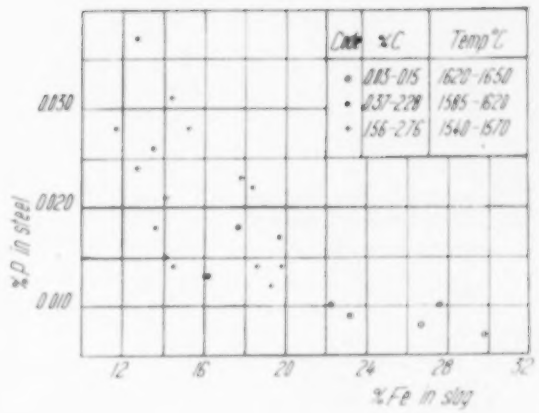


Fig. 12—Relation between phosphorus content of steel and iron content of slag when refining hot metal with 0.2 pct P.

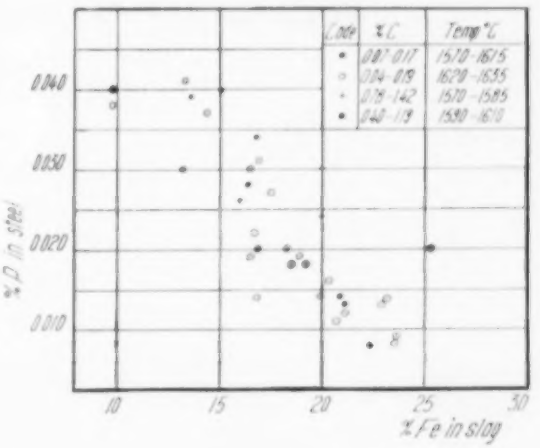


Fig. 13—The same as Fig. 12 for hot metal with 0.66 pct P.

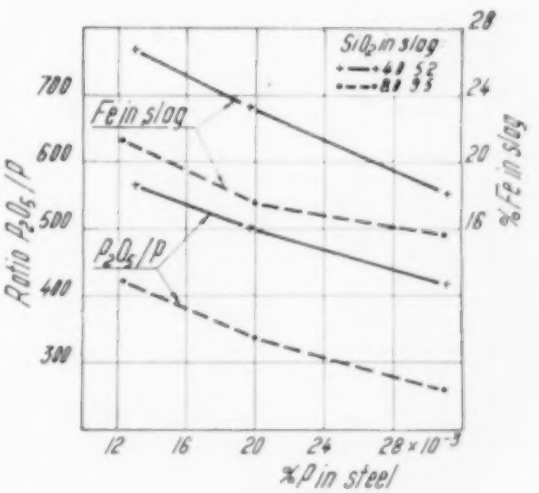


Fig. 14—Iron content and phosphorus distribution at varying silicon contents of the slag.

Discussion of Kaldo Paper

by D. R. Berg
and T. O. Dormsjo

Recent developments in the US and abroad have documented many of the details in the foregoing paper concerning the significant metallurgical control characteristics that are inherent in the Stora-Kaldo oxygen steelmaking process. At the same time, preliminary reports on the operation of a new Stora-Kaldo facility in France show that production results achieved by this process are meeting or exceeding expectations. This facility already has produced what is believed to be the largest single heat —122 tons—ever produced by an oxygen converter of any type. The working volume of the furnace is approximately 2500 cu ft.

In addition to the 110-ton converter operation in France, new Stora-Kaldo facilities are being installed in England and Sweden. The Consett Iron Co. Ltd., in England, recently announced its plans to install two 110-ton converters. Another facility with two 110-ton converters is expected to begin producing steel at Oxelosund, Sweden, early in 1961, and the addition of comparable size equipment is programmed at Domnarvet, Sweden.

The interest of North American steelmakers in the Stora-Kaldo process has been heightened by the combination of three principal characteristics of this oxygen conversion method, as described in the foregoing paper. These are positive process control that assures production of a wide variety of carbon and alloy steels to precise metallurgical specifications, excellent heat economy, and high yields.

Studies made at a Pennsylvania mill with ingots and slabs produced by the Stora-Kaldo process show that the three grades of steel tested—1005 aluminum killed, 1064 fine grain, and 1095 coarse grain—were equal or superior to the mill's own open-hearth steel. Among the factors used in the comparison were ingot-to-slab yield, chemical segregation, magnaflux quality, non-metallic count, hot-roll ductility, and cold-roll annealed ductility. This mill is one of several in the US now evaluating the process with Dravo Corp. and Stora Kopparberg engineers.

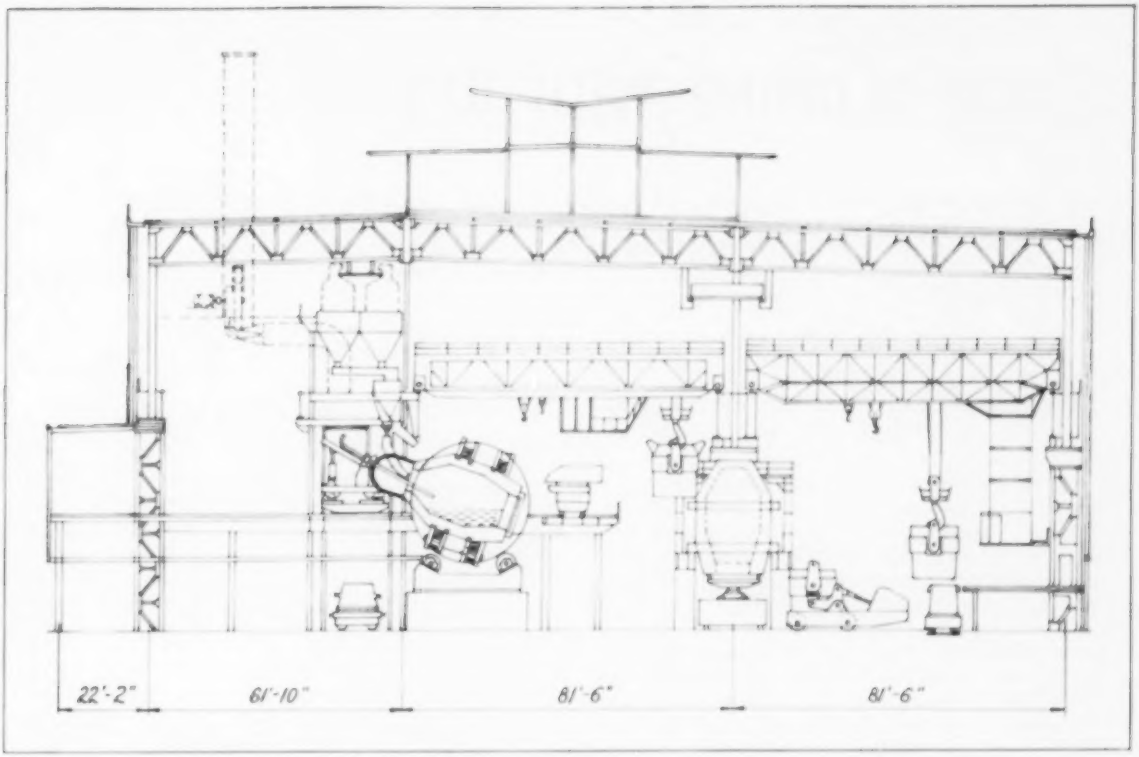
In France, Stora-Kaldo steel is now being rolled into deep-drawing sheets primarily for the auto industry. From hot metal with 3.5 pct C, 0.5 pct Si, 0.35 pct Mn, 1.7 pct P and 0.040 pct S, steel is produced with 0.06 pct C, 0.015 pct P and 0.010 pct S. Using 99.5 pct O_2, the nitrogen content of the steel is low—usually 0.002 pct.

The flexibility of the process that enables it to produce a wide variety of steels to exact specifications consistently is of particular significance to steelmakers who manufacture many different grades. Of equal significance to those who mass-produce only a few grades are the thermal efficiency and high-yield factors of the process. As the foregoing paper states, the price relationship between iron and scrap can fluctuate widely. The heat economy of this process, therefore, enables producers to adjust the balance of feed materials over a broad range to meet existing conditions and still maintain the quality of the end product. The tests in a 30-ton furnace, as outlined in the foregoing paper, have proved that more than 40 pct of the total metallics charged can consist of scrap. Actual experience in a 110-ton unit has demonstrated that approx 45 pct of the metallics charged can be scrap.

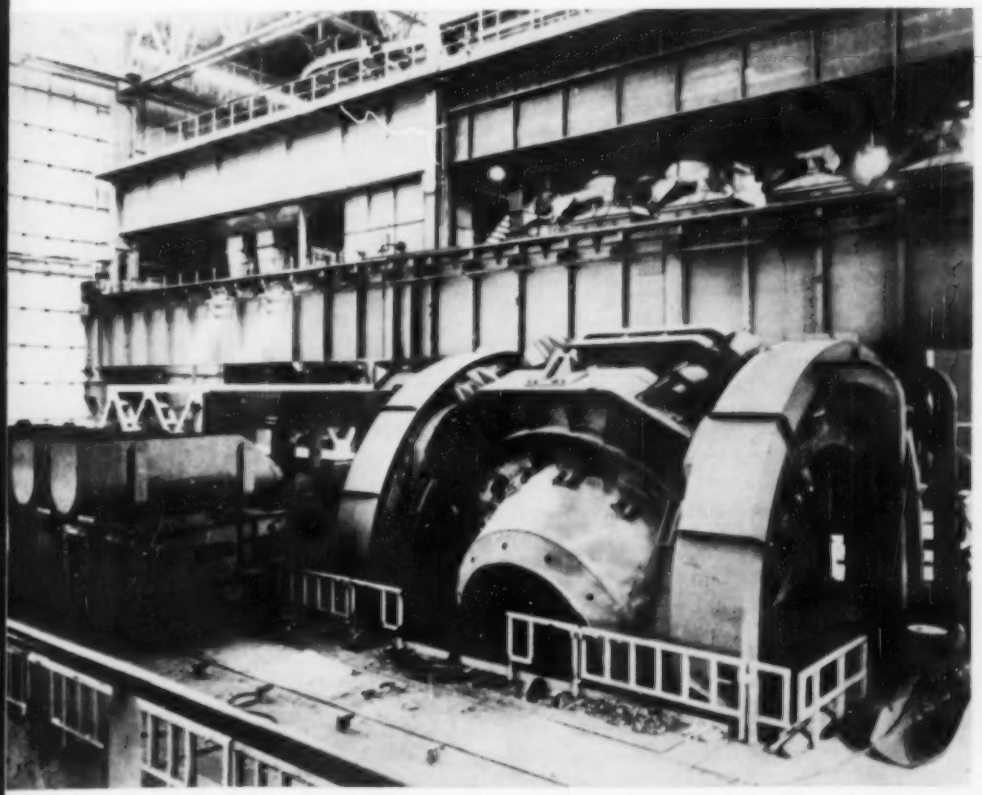
Yield performance is another economic consideration which results from the various operating features of the process described in the foregoing paper. Ladle yield (weight of blown metal divided by weight of total metallics charged and added) at the Sollac plant in France has been 93 pct when using 40 pct scrap plus some ore as a coolant. This is a particularly good result considering the blowing time and slag volume associated with production of 0.06 pct C, 0.015 pct P steel from hot metal with 3.5 pct C, and 1.7 pct P.

During initial operation of the French 110-ton unit, only one 8-hr shift per day was scheduled. The vessel was permitted to cool down each day for the remaining 16 hr. Also the tap-to-tap time was extended considerably due to training of personnel for all shifts during the 8-hr of daily operation. Slag analyses during this period showed refractory consumption per ton of ingot to be 24 lb using heavy scrap and ore as coolant. With this rate of refractory use and based on present lining design, two vessels could be kept in continuous operation in a three-vessel plant.

D. R. BERG is with Dravo Corp., Pittsburgh, Pa. which holds US and Canadian rights to design, market, and construct Stora-Kaldo facilities. T. O. DORMSJO is with Stora Kopparberg Corp., New York.



Side elevation of Sollac's Kaldo facility in the Lorraine area of France. One of the two 110-ton vessels is shown at left center in the rotating cradle; the other is in position on the relining stand.



In France, Sollac's new Kaldo vessel in blowing position at 17° from horizontal. At left is the scrap charging machine. Burnt lime and ore are charged from overhead bins.

BOTTOM BLOWING WITH OXYGEN

This article describes a new iron refining process which drastically reduces iron oxide fumes. Instead of the top lancing of the LD process, high-pressure oxygen is injected into the bottom of the metal bath through specially-designed injectors. The cooling effect of the oxygen flow itself eliminates the need for an external coolant.

by G. Savard, R. Lee, and M. R. Campbell

As an outgrowth of oxygen lancing tests, employed for desiliconizing iron in the transfer ladle, a new oxygen process for refining iron has been developed by Canadian Liquid Air Co. in conjunction with Dominion Iron & Steel Corp. at Sydney, Nova Scotia. The process employs a bottom-blown converter using pure oxygen at a minimum pressure of 400 psi. Oxygen is introduced into the bottom of the metal bath through a specially-designed injector. No water or external source of cooling is used. Instead, the injected oxygen is employed to keep the injector from disintegrating in contact with the violent oxygen-metal reaction.

Tests began in an attempt to desiliconize hot metal in the transfer ladle by impinging oxygen onto the surface of the metal. Through an extensive series of experiments, adequate oxygen efficiency was achieved, and a tendency of the metal to form layers was minimized. However, another problem was not solved; it concerned the generation of a large volume of iron-oxide fumes.

Subsequent studies concluded that, if the reaction $2\ Fe + O_2 \rightarrow 2\ FeO$ could be effected at or near the bottom of the ladle, the FeO would be reduced by the silicon before reaching the surface, thus yielding the final reaction products of iron and SiO_2 (neglecting reactions with manganese, etc.). In other words, the reaction products, while passing through the molten metal—which acts as a scrubber—could be absorbed, and the volume of iron-oxide fumes reduced.

In 1954, experiments were started to prove this theory and develop an injector design suitable for driving oxygen through the molten bath without resorting to water cooling. These tests pointed to the desirability of multiple injectors, since numerous small reaction zones enclosed by molten metal were found better than one large zone. These injectors resulted in less fumes, less splashing, and improved reaction with the oxygen.

Meanwhile at another plant in Canada, large-scale tests were being carried out on 16 to 38 ton batches of metal, which averaged 1.2 pct C; ferrosilicon was added to give a starting silicon content of 1.07 pct. With an oxygen consumption of 255 cu ft-per-ton, the final silicon content reached 0.28 pct, and efficiency was over 100 pct (based on the silicon oxidized). However, premature injector burn-outs frequently occurred, and the iron *bottom-poured* through the completely eroded injectors. With these tests, and from the previously-mentioned small-scale tests, sufficient data were gained to proceed with pilot-plant work.

G. SAVARD and R. LEE are with the Canadian Liquid Air Co. Ltd., Montreal, Que., Canada. M. R. CAMPBELL is with the Dominion Iron & Steel Corp., Ltd., Sydney, Nova Scotia, Canada. This paper was presented at the 42nd Conference of the National Open Hearth Steel Committee of AIME.

Pilot plant tests

In the pilot plant tests, a 20-ton ladle, lined with standard fireclay ladle brick, was employed as a treating vessel (Fig. 1). The number of courses of brick varied, because various weights of metal were treated, and it was desirable to keep the depth of the bath at a minimum of 3 ft. Oxygen for the pilot plant was supplied by a bank of cylinders, thus making a precise record of oxygen consumption available. The cylinder pressure was regulated to approx 200 psi above delivery pressure and throttled to the desired level by a needle valve near the treating vessel.

The success of the process hinges on the appropriate oxygen pressure, and the design of the refractories and the injector assembly. The injector must withstand: a) the washing action of molten metal and oxides; b) the highly exothermic reaction of molten metal and oxygen; and c) total immersion into the molten metal. Since there is no other means of cooling, the oxygen flow must keep the injectors from disintegrating. It does not require very high pressure to keep the metal from flowing into the injectors; hence, the pressure is controlled so as to maintain an optimum oxygen flow for cooling.

Desiliconizing hot metal

The first phase of pilot-plant work was carried out at the Sidney plant of Dominion Iron & Steel Corp. in 1956 and 1957. Its purpose was the desiliconizing of hot metal to a consistently low level through the high-pressure oxygen injection technique.

The weight of metal at the start of the program was approx 4 tons; however, it was progressively increased until 12½ to 15½ tons were treated.

The pilot plant was set up at the mixer end of the open-hearth shop, where the hot metal was transferred by standard ladles. A metal sample for chemical analysis was first taken, followed by a thermocouple temperature reading. The treating

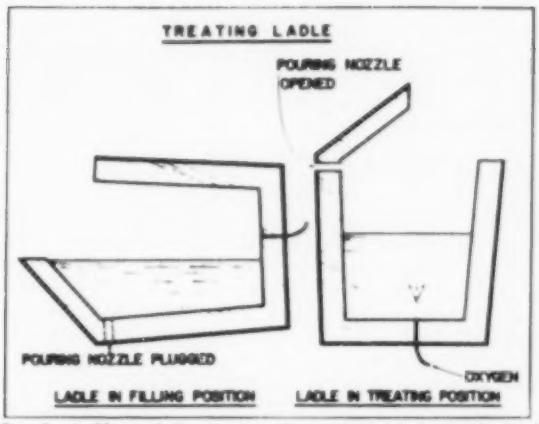


Fig. 1—A 20-ton ladle, lined with standard fireclay ladle brick was employed for pilot tests.

vessel was then lowered to the horizontal filling position, and after the filling was completed, it was rotated back into the vertical blowing position. Meanwhile, oxygen was blown through the nozzles at full flow. Until the injectors were completely submerged, the oxygen impingement on the surface of the molten metal caused a vigorous reaction, ejecting metal particles as far as 30 ft. When the injectors were immersed, the reaction quieted down and the amount of splash and fume decreased.

Fluxes were added at the beginning, and if necessary, also during the blowing period; the vigorous mixing action caused the fluxes to be completely dissolved within 5 min of their addition. Experience showed that, when the silicon content reached approx 0.2 to 0.3 pct, the oxygen reacted with the carbon, giving the visual indication shown in Fig. 2. Agitation of the bath became more predominant and the carbon monoxide flame noticeably increased. In fact, if a constant record could be kept on the silicon content of the hot metal in the mixer, this treatment could be done on a time basis.

When the metal was desiliconized to the desired level, the vessel was rotated to the horizontal filling position; a temperature reading was taken, followed by a metal and slag sample. After this, the metal was poured into a pit ladle and then back into the hot metal ladle. It was topped with the required weight of untreated metal from the mixer, and then charged into the open-hearth furnace.

Results

The results shown are based on the average of nine consecutive heats carried out at the end of the program, and were considered typical. The average weight of metal treated was 14.9 tons. The flux consisted mainly of mill scale (1.8 pct) and burned lime (1.5 pct); a small quantity of fluorspar (0.14 pct) was also added.

Table I summarizes the tests with 4 injectors in parallel, each admitting approx 56 cfm oxygen flow. The temperature of the metal during blowing increased from 2315°F to 2545°F. Based on the injection time of 14.4 min (shown in Table I), the rate of temperature pickup was about 16°F per min. Table II lists the metal analyses before and after treatment. Silicon drop amounted to 4.5 points (or 0.045 pct) per min. Noteworthy is the fact that ¾ of the silicon content was oxidized, compared to about ½ of the manganese.

The following was a typical slag analysis at the end of the oxygen treatment: 23.80 pct CaO, 52.80 pct SiO_2, 4.13 pct FeO, 12.75 pct MnO, 5.79 pct MgO, and 0.15 pct P_2O_5. Composition varied with the amount of flux added and the silicon and manganese removed. Although complete analyses were made for only eight heats, the FeO and MnO were determined for every slag; these averaged 5.19 pct FeO and 10.93 pct MnO.

The thorough mixing action created by the bottom-injected oxygen permitted mill scale to be reduced by the metal bath, thereby supplying both oxygen and iron to the molten metal. The mixing action also helped the rapid formation of a fluid slag.

Oxygen and iron from mill scale

In determining the volume of oxygen derived from the mill scale, several assumptions were made:

1) the oxidized manganese of the hot metal entered the slag as MnO;

2) mill scale was 100 pct Fe_2O_3; and

3) the FeO content of the slag resulted from the partial reduction of mill scale, while the remaining mill scale reacted with the metalloids in the bath.

On this basis, the oxygen added to the process by the reduction of mill scale was 130 cu ft per ton, but oxygen from mill scale remaining as FeO in the slag was 12 cu ft per ton. Thus, the oxygen which reacted with the metallic bath amounted to 118 cu ft, i.e., 91 pct of the oxygen added in the form of mill scale. Adding this figure to the oxygen injected (shown in Table I), the total oxygen flow into the metal was 339 cu ft per ton, and about 35 pct of the total oxygen was derived from mill scale.

On the same basis, 25.2 lb Fe per ton of iron was added to the metal bath in the form of mill scale. Since it was assumed that the FeO in the slag was derived from the partial reduction of mill scale, the FeO in the slag accounted for 3.5 lb Fe. Thus, 21.7 lb Fe per ton of iron was absorbed by the metal bath from the added mill scale, which is about 81 pct recovery. This pickup more than compensated for the decrease in weight due to oxidation of silicon and manganese.

The oxygen efficiency—based on the analysis of metal shown in Table II and on the total oxygen added to the bath (from injection and reacting mill scale)—was 87 pct. It is not possible to visualize free oxygen escaping under such ideal conditions for chemical reactions; however, using the conditions imposed for the efficiency calculations, this was the figure obtained.

The work on desiliconizing iron with the high-pressure bottom-injection technique seems to indicate the possibility of consuming all the mill scale

Table I. Data on Oxygen Injection for Desiliconizing Tests

O_2 per heat, cu ft	3293
O_2 per ton, cu ft	221
Duration of Injection, Min	14.4
Rate of O_2 flow, cfm	229

Table II. Analyses of Metal in Desiliconizing Tests

	C, pct	Si, pct	Mn, pct	S, pct	P, pct
Before Treatment	4.09	0.85	0.74	0.045	1.10
After Treatment	3.81	0.20	0.37	—	—

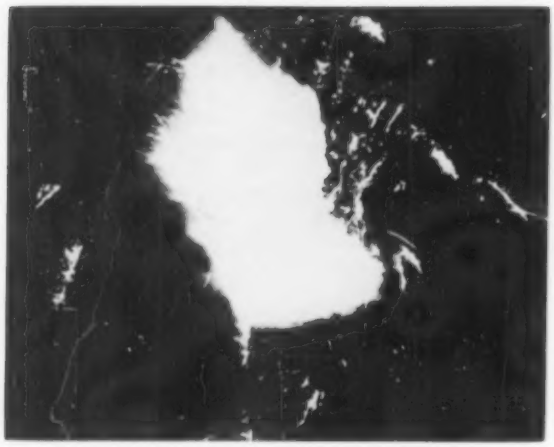


Fig. 2—Carbon oxidation commences at about 0.2 to 0.3 pct Si.

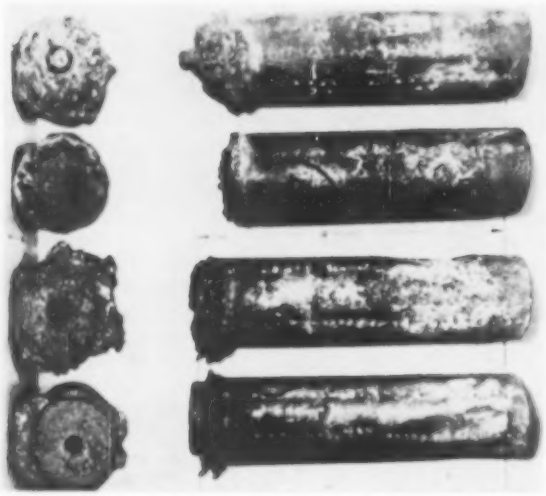


Fig. 3—Injectors used in pilot plant runs. Detailed discussion of conditions encountered by these injectors is given in article.

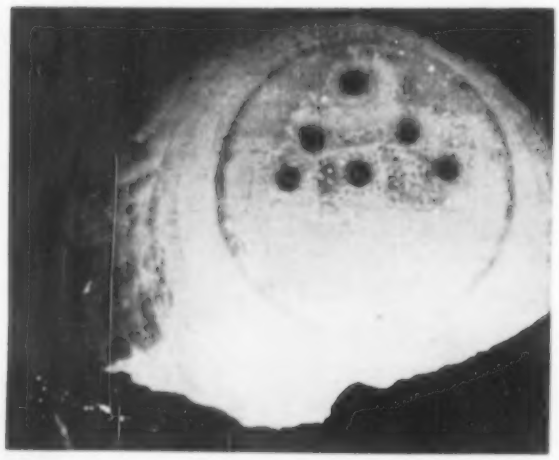


Fig. 4—The bottom of ladle, 5 min after injection treatment was terminated.

generated in an average mill. Of course, for certain silicon drop, the temperature pickup of the treated iron decreases with increased amount of mill scale. However, the intimate agitation created by bottom blowing provides flexibility for large variation of flux additions.

Decarbonizing high-carbon iron

A program to decarbonize high-carbon iron by oxygen injection was carried out at the foundry of Sorel Industries Ltd., Sorel, Quebec, Canada. The purpose was to lower the carbon content to a value suitable for further processing in the arc furnace and to evaluate the bottom injection process for refining the metal to specification without use of duplexing. Using the same pilot plant installed at Sidney, 10 heats were blown before hot charging into an 8- or 20-ton basic-lined arc furnace. Since the starting temperature of the iron was on the low side in some heats, ferrosilicon and ferromanganese were added at the start of the oxygen blow in order to arrive at a higher final temperature.

The analysis of the iron prior to blowing was 2.3 pct C and 0.05 pct max S, with very low concentrations of silicon, manganese, phosphorus, copper, tin, and other trace elements. Some of the heats were blown to approx 0.3 to 0.5 pct C, and one to the end point. Metal samples and temperature readings were taken before and after oxygen injection. The decarbonized metal was tapped into a transfer vessel and charged into the arc furnace for further refining.

The average reduction in carbon content was 1.9 pct, with a final carbon content of 0.4 pct. A wide scatter of results was found, since for most tests the starting carbon was not known until after oxygen injection. Most of the silicon and part of the manganese, added at the start of the injection, were oxidized.

The volume of oxygen injected avgd 716 cu ft per ton of iron. Based on the theoretical oxygen requirements for the oxidized amount of carbon, silicon, and manganese, the efficiency was 93 pct. Starting temperature varied from less than 2400°F to over 2600°F; final temperature was between 2650°F and 3040°F. An average additional 90°F increase in temperature was obtained by the addition of 0.35 pct Si.

The metal can be partially refined by high-pressure oxygen injection and charged into the arc furnace for further refining. It also can be converted to steel without additional refining; however, for this series of heats the arc furnace provided the required control of chemical composition for an order of special low-alloy steel.

Injector performance

One of the first relationships discovered was that injector burn-off rate was a function of the injector wall thickness. For example, using oxygen at 400 psi, copper injector tubing with an orifice diam of 1/16 in., and a super-duty fireclay refractory injector shield, an injector of 3/32 in. wall thickness did not burn, whereas a wall thickness of 1/32 in. resulted in a burn-off of ¼ in. per min.

Another important factor discovered was the choice of refractory surrounding the injector. For the above conditions and for ⅛ in. OD injector tubing, the corresponding burn-off rate when employing burned-magnesite as refractory was 2 in. per min.

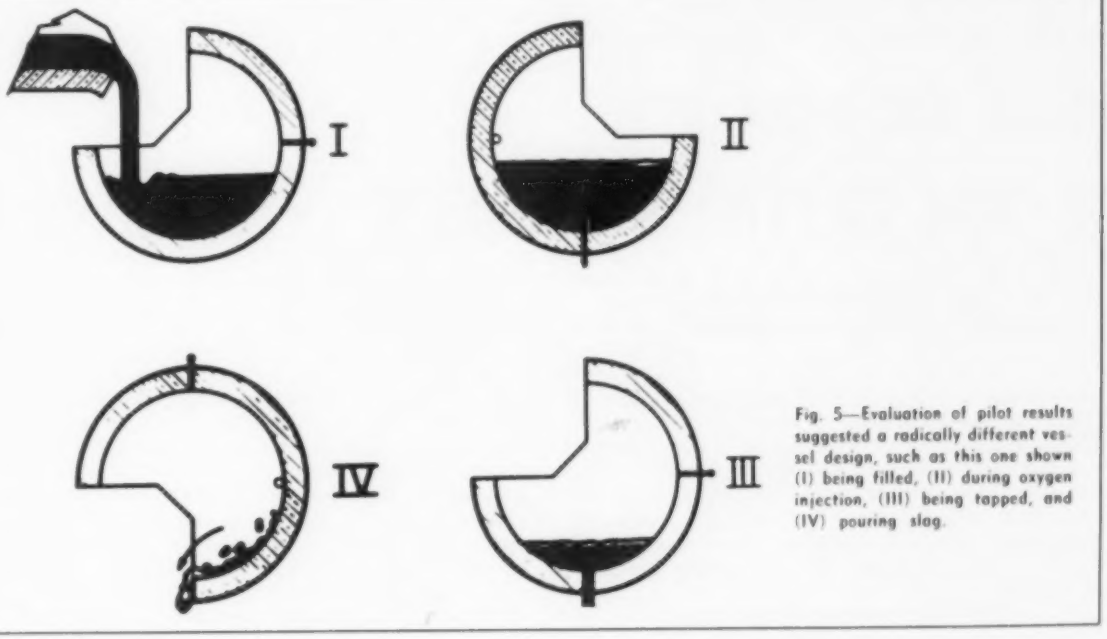


Fig. 5—Evaluation of pilot results suggested a radically different vessel design, such as this one shown (I) being filled, (II) during oxygen injection, (III) being tapped, and (IV) pouring slag.

Fig. 3 shows some of the symptoms, which were encountered by the injectors. Starting length of all injectors was 12 in. The top injector, with the tubing projecting above the refractory, shows that the weak link lies in the refractory around the injector. The protruding portion of the metallic tubing was protected by a coating of frozen metal and slag. The second injector from the top shows that the tubing has eroded more rapidly than the refractory, creating a cone-shaped hollow with the injector tubing at the apex. This can be caused by the following factors: 1) poor injector material; 2) incorrect wall thickness of injector tubing; 3) insufficient cooling due to insufficient oxygen pressure; and 4) spalling of the refractory immediately adjacent to the injector tubing.

The refractory surrounding the third injector is in good condition, as is the tubing itself. In fact, it was cooled sufficiently by the oxygen to freeze metal onto the injector tubing. The bottom injector shows the tubing intact after the solid metal was removed from the tip. In some cases the injector tubing surface in contact with the metal was inscribed with an *X*, which remained intact during service.

Oxygen pressure

The choice of operating pressure depends on many factors. It is not possible to give exact figures; however, as a guide in desiliconizing hot metal a pressure greater than 400 psi is necessary to avoid burn-off. When higher temperatures are encountered, as in refining high-carbon iron where the final temperature is over 3000°F, a pressure higher than 600 psi is necessary. In some instances, heats were treated at over 1200 psi oxygen pressure.

Refractory and vessel design

The only reliable data available on the erosion of the vessel lining is based on 26 desiliconizing heats at Sidney. At the slag line, where the erosion was the greatest, the standard ladle brick eroded about ½ in. By controlling flux additions so that the slag never becomes too basic, this erosion could be reduced. Considering the fact that the brick lining was only standard ladle brick, the erosive action of the slag can be considered very small.

The present treating vessel does not permit the injectors to be distributed uniformly throughout the bottom. When six injectors are used in parallel, the injectors are concentrated on one half of the bottom (Fig. 4). The picture shows the bottom of the ladle 5 min after the injection treatment was finished; the small round dark areas represent the cool regions surrounding the injectors, while the lighter region is the glowing red-hot fireclay lining.

Conclusions

By dividing the total oxygen flow into a series of multiple jets, intimate contact between the oxygen and metal was achieved—although the evaluation of the factors suggests a radically different vessel design (such as shown in Fig. 5) from the one used in the pilot plant tests.

If the bath is sufficiently deep, the oxygen efficiency will be high and iron oxide fumes will be reduced to a minimum. The multiple reaction zones in the bottom of the vessel produced agitation, which by nature has little wear on the refractory lining. In fact, even with standard ladle fireclay brick there was little erosion.

The combination of ladle design and bottom blowing affords good control of the blowing operation: the carbon can be stopped at any point, thus making the process available to the whole range of carbon steels.

The injection of high-pressure oxygen at the bottom of the treatment vessel without attendant water cooling of the injectors requires simple installation. If the injector performance proves to be reliable on an industrial scale capital and maintenance costs should be reasonable, thereby making it attractive for producers.

CHICAGO... NOHC AND BFCORMC OF TMS OF THE AIME MEET!

This is a review of the technical and social events of the 43rd Conferences of the National Open Hearth Steel Committee and the Blast Furnace, Coke Oven, and Raw Materials Committee . . . held in Chicago during the first week of April 1960.

Gathering in the corridors and meeting rooms of the Palmer House in Chicago April 4-6 were registrants to the 43rd Conferences of the National Open Hearth Steel Committee and the Blast Furnace, Coke Oven, and Raw Materials Committee. Interest ran high in discussions of old and new iron- and steelmaking processes, as the attendance barometer (topping the 2000 mark for the first time) well attests.

The meeting proceeded with the usual array of dynamic extra-curricular flare, à la Chicago by night. But by day more serious business took place. One such event was the Annual Luncheon and Business Meeting of the Blast Furnace, Coke Oven, and Raw Materials Committee. The time was 12:30 pm on Tuesday, April 5th; the place, the Crystal Room. R. E. Powers, chairman of the Committee, reported on substantial progress being made in numerous fields of endeavor. These include an expanded technical program, particularly in the area of coke-oven and byproduct operations. Consideration is being given to the establishment of additional awards, and efforts are being made to decrease the time required for publication of the Proceedings volumes, but work on the establishment of local sections is proceeding slowly. W. F. Huntley, secretary of the Committee, read the minutes of the previous meeting. W. O. Bishop of the finance committee told of progress being made in advertising in the Proceedings, and Committee treasurer, R. W. Shearman, painted a rosy picture. The program committee was complimented on its fine work, and the meeting moved on to nomination and election of officers. The results were as follows: James Chisholm, chairman; W. F. Huntley, second vice-chairman (two years), D. C. Brown, secretary; W. O. Bishop, director (four years); and E. R. Dean, director (four years).

Fellowship Dinner

Charging sequence for the Annual Fellowship Dinner went from illuminated seafood cocktail through a variety of burden to petit fours and coffee. Welcoming remarks were by M. E. Nickel, chairman of the Chicago NOHC section. D. R. Loughrey next took the chair as head of NOHC in order to present thanks and best wishes to past-chairman, V. W. Jones, who has since passed away. Leo F. Reinartz received the presentations on behalf of Vernon Jones. Dan Loughrey presented the *McKune Award* to W. P. Connor and D. J. Miller of Jones & Laughlin Steel Corp. for their paper, *Aluminum Capped Steel*. And the Conference Award went to R. A. Hinnebusch and J. A. McKinnon of United Engineering & Foundry Co. for their paper, *A Practical Method for Statistical Evaluation of Open-Hearth Problems*.

On behalf of the Blast Furnace, Coke Oven, and Raw Materials Committee, R. E. Powers presented the *Journal of Metals Award* to Y. C. Chang of U. S. Steel Corp. for his paper entitled, *Optimum Operation in the Recovery of Light Oil*. A certificate of thanks was given to past Committee chairman, J. W. Duncan for his fine work.

Bob Powers presented to AIME President, Joseph L. Gillson, a check for $1000 for the United Engineering Center Building Fund . . . and this was followed by Dan Loughrey with another $1000 check on behalf of the NOHC . . . and in the stampede a third check for $1000 was presented by Paul R. Gouwens of the Electric Furnace Committee. Somewhat overcome, President Gillson accepted the checks with strong expressions of thanks to the three committees.

Toastmaster of the evening, E. C. Logelin of U.S. Steel Corp., presented the speaker of the evening, James C. Downs, Jr., chairman of the Real Estate Research Corp. Mr. Downs' realistic approach to our present economic situation was well received by the audience.

Technical Sessions

A wide variety of technical sessions, stressing both the practical and the theoretical aspects of iron- and steelmaking, were held. In the open-hearth meetings, consideration was given to safety, ultrasonic testing, statistical and computer analyses of operating problems, oxygen roof lancing, and refractories. An interesting paper on a new vacuum process for treating molten steel, the DHHU process, was presented at the Operating Metallurgy session, and published in the May issue of JOURNAL OF METALS. A great deal of interest was engendered by the Basic Oxygen Furnace Operating and Refractories session, and the JOURNAL OF METALS is publishing several of these papers in this issue.

In the Blast Furnace, Coke Oven, and Raw Materials Conference, considerable emphasis was given to coking coals, coal chemicals, and coking problems. And the JOURNAL OF METALS expects to publish some of these papers during the ensuing year in order to increase its coverage of this area. A session on Iron Ore Reduction proved particularly interesting and produced two papers which were published in the April issue of the JOURNAL OF METALS: *The Alan Wood H-Iron Plant*; and *Direct Reduction of Fine Iron Concentrates in a Self-Agglomerating Fluidized*

Bed. Blast Furnace Practice and Theory sessions, a Sintering session, a Computer Simulation session, and a Joint session with emphasis on the hot-blast cupola in the steel industry rounded out the sessions.

Three award-winning papers were presented at the conferences, and these are summarized in the following paragraphs:

Conference Award

A Practical Method for Statistical Evaluation of Open-Hearth Problems, by R. A. Hinnebusch and J. A. McKinnon, United Engineering & Foundry Co.

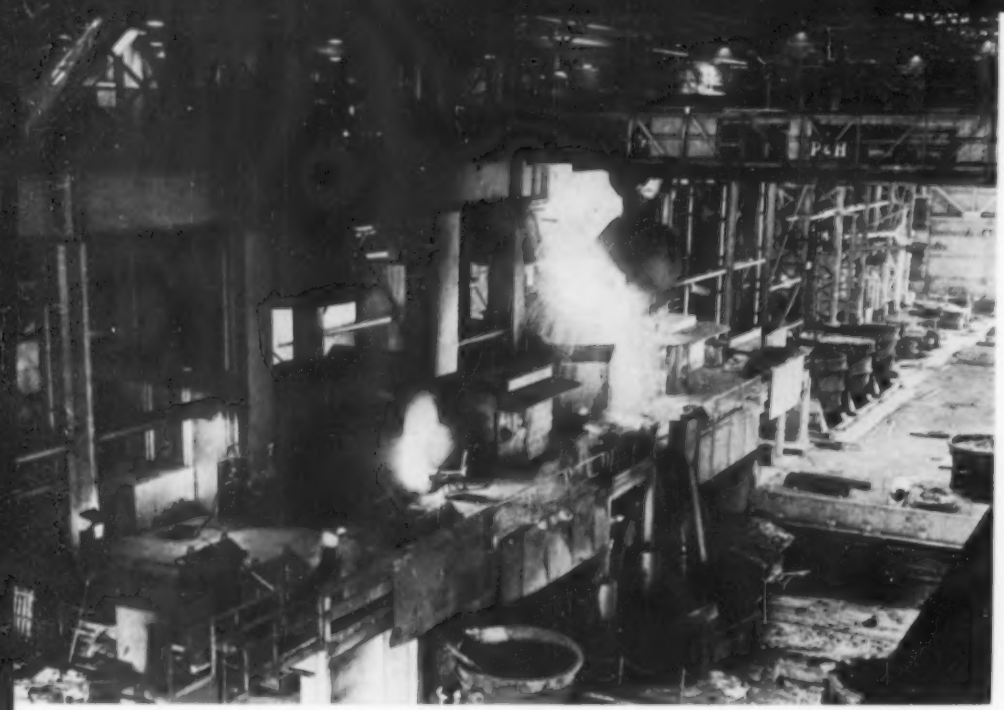
This paper describes a quasi-statistical method designed to furnish simple graphical solutions to typical shop problems. Most problems require the evaluation of the effects of a number of independent variables acting upon some dependent variable. This type of evaluation is possible when using a statistical method known as *multiple regression evaluation.* When modified by graphical interpretation of the data, this method can be utilized to produce practical, workable solutions with a fraction of the effort and frustration inherent in the pure statistical approach.

The graphical solution uses a regression line, which is described as a line which represents the average relationship existing between two variables shown on a scatter diagram. In statistical work, the equation of the regression line is usually determined by the *method of least squares.* There is nothing wrong with this method, except that it is time-consuming or requires the use of calculating machines. The regression lines used by the authors were determined by the method of *selecting points* in which a straight line is drawn which appears to give the most equitable distribution of plotted points around it. The authors also employed some simplication of the correlation factor in their computations.

In order to illustrate the method, the authors studied the recovery of manganese in chrome-molybdenum steels. Production records were obtained for six variables, and the manganese recovery obtained in each heat was calculated. Scatter diagrams were constructed to show any relationship existing between the variables and the manganese recovery. The graphical interpretation of the data confirmed the importance of two variables: go-ahead temperature and finish slag length.

The next step was to investigate the relationship existing between the two variables and the manganese recoveries of a series of chrome-molybdenum steels having an extended range of *go-ahead carbon levels.* This permitted the construction of a control chart suitable for a much wider field of application.

Left, NOHC and its award winners; shown (l to r) L. W. Moore, 1960 chairman; D. R. Loughrey, 1959 chairman; J. A. McKinnon, co-author of the Conference Award paper; and W. P. Connor and D. J. Miller who received the McKune Award. Below—left, Y. C. Chang receives the Journal of Metals Award from R. E. Powers. Below—right, R. E. Powers gives AIME President Joseph L. Gillson $1000 for the United Engineering Center Building Fund.



The basic oxygen steel plant of Acme Steel Co. was toured by almost 500 conference registrants.

Recovery equations were derived and expressed as charts in which the finish slag lengths appear as a family of straight lines on a plot of go-ahead temperature vs manganese recovery. These control charts have been used in actual operation for a period of six months and have resulted in a 75 pct reduction in off-specification heats.

This statistical-graphical method can be used whenever the problem involves the correlation of two or more variables and, consequently, can be a useful tool in quality control programs. The method is simple and requires no specially-trained technicians or costly equipment.

Journal of Metals Award

Optimum Operation in the Recovery of Light Oil, by Y. C. Chang, U. S. Steel Corp.

The recovery of light oil is an inherent part of the operation of a coke-oven plant. The problem of how to operate such a recovery plant at a maximum profit is naturally of great interest to the coking industry. Although various methods are used commercially for the recovery of light oil, the wash-oil absorption process is the most popular, at least in the US.

The author defines *optimum operation* to mean the maximum net return within a certain period of time. By this definition, when the total value of products and the total recovery costs are plotted as ordinates vs some appropriate variables as the abscissas, the point of maximum net return occurs where the vertical distance between the income curve and the cost curve is the largest.

To facilitate the analysis of such a complex process as that of wash-oil absorption, the relevant economic factors and process variables are simplified whenever possible. Income is made up of the revenue from the sales of the three major products of light oil: benzene, toluene, and xylene. The cost of recovery consists of fixed costs, such as depreciation, and variable costs, such as steam. Since the author is interested in locating the optimum point of the operation and not particularly in the absolute value of the profit, simplicity can be gained at no expense of accuracy if only relative values are employed. For this reason, the fixed costs are not included in this treatment, and the variable costs alone are considered.

The total variable cost is determined by the sum of three items: steam, electricity consumed by motors driving the circulation pumps, and refining costs. Steam represents a large fraction of the variable cost, for steam is used not only within the stripper, but in most plants also in the final heater to bring the temperature of the feed up to the desired level. The cost of refining is considered proportional to the quantity of the three products produced. Other variables are relatively small and are not considered by the author.

The relative net return, exclusive of fixed costs, is the total value of the product minus the sum of the three major variable costs, which can be defined by equations relating fractional recovery and operating variables for the absorber and stripper. The maximum value of the relative net return, N, can be obtained either analytically or graphically with the equations given in the paper, but the graphical procedure is simpler and more straightforward. This procedure is illustrated by the author in a hypothetical case. Since this hypothetical case is typical insofar as the equipment arrangement is concerned, this method is applicable to commercial plants.

McKune Award

Aluminum-Capped Steel, by W. P. Connor and D. J. Miller, Jones & Laughlin Steel Corp.

The concept of an economical grade of steel with the favorable rolling characteristics of rimmed steel, plus the reduced segregation found in killed steel, led to experimentation with chemically-capped steel. The term *chemically capped* is used to denote a practice wherein the action of a poured rimming ingot

is completely suppressed by the addition of a strong deoxidizer, such as aluminum or silicon. The product might be described as rimmed steel stabilized after a predetermined rimming period. The term *aluminum capping*, as used by the author, pertains to a practice of killing the core of a rimming ingot after the rim action has been allowed to progress for about 3 min.

In mid-1957, experimentation was begun at Jones & Laughlin's Cleveland works with aluminum-capped steel. Initial development work was on the basis of single ingots. Moving carefully, and not without problems in developing an optimum deoxidation practice, production was increased to a full-heat basis. A review of the mill processing of the first 50 production heats indicated that cold-rolled sheet produced with aluminum-capped steel was equal to or superior to regular rimmed steel.

In the fourth quarter of 1958, it was decided to incorporate the results of previous studies made on this grade of steel into one comprehensive comparison of the two steelmaking practices. In order to accomplish this, two adjacent parts of ingots were selected from the same deep-drawing rimmed heat. The first ingot in each pair was permitted the normal rimming interval prior to conventional plate and water capping. The second ingot in each pair was aluminum capped for comparison.

The first pair of ingots was split, drilled for check analysis, and macro-etched, to permit an evaluation of segregation characteristics and porosity patterns. The second pair of ingots was processed into cold-rolled sheets to permit a comparison of sheet properties. This study included the following considerations: chemical homogeneity, ingot soundness, ingot-to-slag yield, sheet surface quality, sheet physical and chemical properties, and sheet microstructure. Details of all of these tests are given in the paper.

The authors go on to point out that customer fabrication of some 120,000 tons of aluminum-capped steel into deep drawn parts has conclusively proved this product to be quite satisfactory in the field. Based on these favorable results, production has steadily increased from 10,000 tons during the experimental period of 1957, to 79,000 tons for the first half of 1959.

Aluminum capping has afforded a sounder ingot, with an increased product yield on the order of 2 pct. The porous, segregated ingot tops, characteristic of regular rimmed products, are minimized without losing the rimmed steel surface advantage.

The harmful effect of sulfur segregation on drawability has been one of the most serious drawbacks of rimmed steel. With aluminum capping, the degree of sulfur segregation has been substantially reduced, being only one-third that normally found in a rimmed ingot. This practice has virtually eliminated the segregated core characteristic of sheet product from the top 35 to 40 pct of a rimmed ingot, and although somewhat finer grained, the aluminum-capped product has more uniform physical and chemical properties. As a result, aluminum-capped steel has made it possible to reduce top-cut discarding on some of the more severe stampings.

The visitations

Plant trips were scheduled for Wednesday, April 6th. Registrants had a choice between the Indiana Harbor plant of Inland Steel Co. or the Riverdale plant of Acme Steel Co.

Acme Steel

At Acme Steel Co., the new hot-blast cupola and oxygen steelmaking facilities were visited. This new mill has been designed to produce 450,000 tons of ingots per year. It is equipped with two cupolas and two LD vessels, which are rated at 50 tons capacity, but actually produce about 70 tons-per-heat. Production is at the rate of 20 heats per day, averaging 75 tons-per-hr.

Acme is a strip steel producer, and residuals must be watched carefully. Usually 40 pct iron is charged into the cupolas. This may consist of only 20 pct pig iron, with the remainder car wheels or briquetted cast-iron borings or turnings. The 60-pct steel scrap charged consists of revert scrap, bundles, and #2 heavy melting scrap. No ferroalloys are charged. The coke usage is approx 13 to 14 pct of the metallic charge, and the slag volume is between 5 and 8 pct. Lime: silica ratios run from 1.4 to 1.8, depending upon the amount of desulfurizing required. Sufficient fluorspar is used to obtain a fluid slag.

More than 1100 heats have been made in the LD vessels. No heat has been scrapped, and there is no off-grade ingot inventory. All grades of carbon steel, which are customarily produced in an open-hearth, have been produced. Rimmed, semi-killed, and hot-top ingots are made with carbon running from 0.05 to 1.00 pct. Some steel with 1.40 pct Mn has been made, and fully-killed aluminum steel is common. Steel quality has been good. A little scarfing is required on the slabs, but none on the billets, which are rolled directly from the ingot.

The laboratory is very close to the furnaces. It has a 20-dial, direct-reading spectrograph, and there is rapid volumetric equipment for carbon and sulfur determination. Iron samples normally are run every hour, and cupola slags are run every 2 to 3 hours. At least one preliminary analysis is made on every heat of steel.

Furnace linings have been lasting from 100 to 150 heats, but it is expected that this will improve in the near future.

Inland Steel

At Inland Steel Co., visitors were shown through the sintering plant, which includes a new Dwight-Lloyd machine designed to treat 4000-tpd of ore fines. In addition to the new strand, the sinter plant contains two 6-ft wide machines capable of making 2200 tons of sinter per day. The new unit is 8 ft wide and 168 ft long with 1344 sq ft of grate bar area and has 21 windboxes. It is located north of the existing plant on new fill, formerly part of the boat turning basin.

The hosts provided an opportunity for visiting the blast-furnace plant before treating their guests to luncheon.

Homeward bound

Thus, after two days of technical meetings and one day of plant visits, to say nothing of outside glimpses of Chicago, registrants to the 43rd Conferences of the National Open Hearth Steel Committee and the Blast Furnace, Coke Oven, and Raw Materials Committee turned their sails toward home . . . a little tired . . . but feeling that they had been to a good meeting.

Phases and Processes

HIGHLIGHTING CURRENT DEVELOPMENTS IN METALS

HIGH-TEMPERATURE METALS

by C. A. Krier of Battelle Memorial Institute

METALS of primary interest in this column, in order of decreasing melting point, are: tungsten, rhenium, osmium, tantalum, molybdenum, iridium, columbium, ruthenium, hafnium, rhodium, vanadium, and chromium. Because high temperature has different meanings to different people, other metals will be considered as their inclusion is warranted.

Extractive metallurgy is the art and science of obtaining pure metals. This oldest, and yet in many ways newest, frontier of techhnology embraces all the physical and chemical steps from mineral and ore processing to the recovery, refining, and purification of metals.

Demands of the atomic and space ages for the *rare* and *exotic* metals in a very pure state have caused a revolution in industry. The classical operations of ore processing are being supplemented by such techniques as fluidized-bed roasting, autoclave leaching and precipitation, ion exchange, liquid-liquid and solid-liquid contacting, chromatography, gaseous diffusion, fused salt electrolysis, electrophoresis, and electron-beam melting. In varying stages of research are: leaching with microorganisms (bacterial metallurgy), high-intensity arc melting of ores, the use of solar furnaces as heat sources, irradiation of ores, nuclear blasting (Project Plowshare), and radioisotope tagging of reagents and materials in extractive-metallurgy processes. L. W. Coffer[1], who recently became Director of the Australian Mineral Development Laboratories, reported on several of these newer techniques and their application in commercial practice.

The revolution in the practice of extractive metallurgy is causing an evolution of a new curriculum by which extractive metallurgists are trained. Physical chemistry is becoming more of a *main course* than a *side dish*. Thermodynamics (where is a system going) and kinetics (how fast is the system traveling) are rapidly becoming permanent words in the vocabulary of the extractive metallurgist. Whether he will be called a materials engineer or scientist or process metallurgist will be unimportant. Of prime concern is that he must be prepared to understand and direct the complex heterogeneous systems of extractive metallurgy in an economic manner to fulfill the increasingly demanding requirements of a metal-hungry society.

Reviews and Trends

New construction and expansion of mines and processing plants, production, consumption, prices, new developments, and general forecasts for both the major and minor metals recently were given by specialists of the US Bureau of Mines and leaders of several industries[2]. Data on the availability of the refractory metals (the 12 listed above) from the MAB Report[3] and current extraction processes were summarized by Jaffee[4]. Hampel[5] reviewed the occurrence, availability, unusual processing requirements, and applications of rare metals. Gonser[6] summarized the availability, interesting properties, and current and possible future uses of the *newer* metals. Technical developments and trends were summarized by Coffer[1], Franklin[7], and Sherwood[8]. Dannatt[9] reviewed roasting, smelting, hydrometallurgy, electrorefining, and solvent extraction in summarizing 50 years of extraction metallurgy. Relatively new books which have a bearing on extractive metallurgy include two on fluidization, [10,11] *Physical Chemistry and Metal Extraction* by Hopkins[12] and *Extractive Metallurgy* by Newton[13].

Lower cost and high purity are being demanded and sometimes required by the users or potential users of high-temperature metals. These two requirements are usually incompatible.

To cut costs, research is being done to use existing processes more efficiently and to develop new and more direct processes with fewer steps from the ore to the pure metal. Demand for the product traditionally has provided the stimulus to do research. Metallurgists, chemists, and ceramists are working feverishly at present to develop high-strength alloys and protective coatings for these generally non-oxidation resistant alloys of the refractory metals. When the breakthroughs are made, the demand for the product is expected to be much greater than at present, particularly for tungsten, tantalum, molybdenum, and columbium.

Purity is the key to ductility in many of the refractory metals, and ductility is the key to ease of fabricability into usable hardware. There are two problems involved here: 1) extracting the metals to a pure state, and 2) maintaining their purity during and after processing into the desired products. The second problem is being overcome in several ways, with perhaps the most advanced and recent solution being the fabricating mill enclosed in an argon-filled room being built by Universal-Cyclops Steel Corp. for the Navy's Bureau of Aeronautics.* Electron-beam processes[14] recently have been given much of the task of refining *pure* metals to a purer state. About two years ago these processes were a laboratory curiosity; today they are being used for production. Most of the columbium now being produced, for example, is melted in electron-beam furnaces. Early in 1959 Wah Chang Corp. purchased an electron-beam furnace from Stauffer-Temescal Co.; in September 1959, plans were announced to install a second furnace. A dozen companies are hard at work exploring other commercial possibilities.

Alloyd Research Corp.[15], under contract with the Navy's Bureau of Aeronautics,* has been doing research on the production of high-purity molybdenum, tungsten, and tantalum by the hydrogen reduction of their respective halides. Chromium also has been under study.

Extraction Processes and Research

Chromium: Super-pure (99.997 pct) chromium metal, *Iochrome*, is being made by an iodide decomposition process developed by Battelle Memorial Institute under sponsorship of Chilean Nitrate Sales Corp. and now acquired by Chromalloy Corp.[16] A tensile ductility of 44-pct elongation and 78-pct reduction in area was obtained in a room-temperature test on wrought material from an arc-cast ingot of Iochrome. High-purity chromium is useful in the development of higher chromium content super alloys.

Columbium: The market for columbium appears to have potential for substantial growth in the next five years. The rate of growth will depend primarily on the results obtained from the abundance of re-

search currently being done to overcome the problem of high-temperature oxidation and to develop high-strength alloys and fabrication techniques[17]. Sandor[18] estimated the future prospects of columbium and reviewed some results from recent research. The recent book by Miller[19] on tantalum and columbium gives a very comprehensive coverage of the technology of these metals, including processing methods in going from the ore to metal.

In anticipation of future use, the Du Pont Co. secured mining claims on 4500 acres of land near Powderhorn, Colo., which contains columbium in the form of pyrochlore[20]. The truly vast reserves of columbium are in the form of pyrochlore, which has been very difficult to beneficiate. Kennecott Copper Corp. is working on a process to unlock pyrochlore deposits. The process, described in US Patent 2,875,896, uses 8 -quinolinol flotation reagent in flotation to upgrade the ore. Starting with an upgraded ore pulp containing 2.36 pct Cb_2O_5, Kennecott obtained a concentrate with 9.72 pct Cb_2O_5 with an 88 pct recovery. According to Kennecott, the process has proved successful on a pilot scale. Sims[21] reported that Wah Chang Corp. and St. Lawrence Mines Ltd., also are believed to have commercially feasible processes for separating columbium from pyrochlore. Chakravarti and Prince[22] reported research on the effectiveness of chlorine gas and carbon tetrachloride in the extraction of columbium from pyrochlore ($CaNaCb_2O_6(F,OH)$) deposits. Thermodynamic calculations also were reported.

K. C. Li, President of Wah Chang Corp., at the 1960 AIME Annual Meeting in New York announced the discovery of a huge deposit of approximately 7.5 million tons of contained columbium in Araxa, Minas Gerais, Brazil. According to the announcement, a unique and simple mechanical process has been discovered for milling the ore to a grade of over 70 pct Cb_2O_5.

Rolsten[23] investigated the kinetics of the iodide process for refining columbium. The rate of deposition of columbium by the thermal decomposition of columbium iodides on an indirectly-heated quartz surface was studied a) with deposition temperatures from 750° to 1100°C, b) with feed material temperatures from 240° to 470°C, and c) with crude columbium with different surface areas.

Plans for the US Bureau of Mines' 1959-1960 fiscal year included 1) accelerated columbium-tantalum research to probe low-grade domestic raw materials as sources for the two metals, 2) expansion of Kroll-process, bomb-reduction, and fused-salt electrorefining studies, and 3) new work on preparing columbium by thermal decomposition, using a method similar to the van Arkel-de Boer iodine process.

Hafnium: The quality of hafnium metal in Wah Chang's commercial production has been improved by a) passing crude hafnium tetrachloride vapor through a fused salt (NaCl-KCl) bath before reduction by the Kroll process and b) melting the metallic sponge into an ingot in an electron-beam furnace[24]. Advantage of the purification via the fused-salt bath is that the hafnium sponge produced can be melted directly to ingot without going through iodide purification. Electron-beam melting lowers the oxygen content to 100-400 ppm.

Molybdenum: A million-dollar plant for open-pit mining of an estimated 5 million tons of molybdenum ore will go into operation in central Sardinia by the end of 1960, according to the engineering firm of Mazzacurati and Giacomelli of Rome. Estimated worth of the molybdenite ore is approximately $800 million. It has been reported that the ore grade averages between 0.5 and 0.6 pct molybdenum.

A molybdenum plant at the Chuquicamata plant of Chile Exploration Co., a subsidiary of the Anaconda Company of Chile, has been put in operation producing molybdenite concentrates from the copper concentrates. This puts Anaconda again in the field of molybdenum production.

Under sponsorship of the Naval Bureau of Ordnance,* Oregon Metallurgical Corp. successfully scaled-up to the semi-pilot plant stage the tin reduction of molybdenite. The process, based on the Nachtman-Poole patents, is reported to produce low-carbon, low-oxygen molybdenum metal[25].

Climax Molybdenum Co. reported that molybdenum of high purity can be produced by direct dissociation of commercial molybdenum disulfide in vacuo at 1600° to 1700°C[26]. Equipment for the process has undergone several cycles of scaling-up and development, and work now in progress utilizes pilot-scale equipment capable of dissociating 160 lb charges of pelletized molybdenite. Analyses of ingots arc-cast from commercial molybdenum powder, hydrogen reduced from ammonium molybdate, and from thermally dissociated molybdenum sulfide, indicate that the levels of chemical impurities in these ingots are essentially similar.

Metals and Residues Inc. announced the invention of a new process for the production of molybdenum metal powder by a rapid, single-stage reduction of molybdenum oxide at high temperatures. According to the announcement, it is estimated that the process increases the rate of molybdenum powder production by a factor of 5 to 8 times over the rates obtainable by current practices.

Platinum-Group metals: Much activity exists concerning uses of the platinum-group metals[27], but little has been reported on new extraction developments. Of the six metals in the group, four are refractory: osmium, iridium, ruthenium, and rhodium. Domestic sale to consuming industries of these four metals increased 50 pct in 1959 over that in 1958. R. I. Jaffee and associates of Battelle Memorial Institute have been carrying out an extensive research program for the Office of Naval Research on the high-temperature properties and alloying behavior of the refractory platinum-group metals. Electron-beam refining is being used to prepare pure research materials. Because of limited abundance, these metals can be considered only for specialized applications. However, as demand is increased by research, activity in mining and extraction should increase.

Rhenium: The availability, recovery, and properties of rhenium were presented by Campbell, Rosenbaum, and Gonser[28]. This metal is inherently rare and probably will continue to be expensive. However, its extremely high melting point and good metal properties indicate a growing use for those applications where a relatively high cost can be tolerated. The flowsheet of the Kennecott Copper Corp. process to extract rhenium from molybdenum sulphide concentrate was given in US Patent 2,809,092. An ion-exchange technique is used. Advantages claimed include greater recovery of rhenium, single-stage roasting, low-cost recovery of rhenium as a by-product at existing operations, and production of rhenium compounds of high purity. The process furnishes NH_4ReO_4 to Chase Brass and Copper Co., where the salt is reduced with hydrogen and the resulting metal is processed to wrought rod, wire, and strip.

Scandium: Newest of the *exotic* metals is scandium (a relative of yttrium in the periodic table, Group III B) with a specific gravity of 3 (comparable to that of aluminum) and a melting point of 1550°C (about 2-½ times that of aluminum). It comes from thortveitite, a mineral which contains about 40 pct scandium oxide. St. Eloi Corp. extracts 99 + pct pure oxide from this mineral by ion exchange. Over 99 pct scandium metal is produced by: 1) dry-fluorination of the oxide, 2) reduction of the fluoride with calcium at 1400°C, 3) vacuum distillation at about 1600°C, and 4) arc melting.

Union Carbide Metals Co., under contract with the Air Force, will study the physical, mechanical, and chemical properties of scandium. It is estimated that the 1 lb of the 99-pct pure metal for investigation will cost $20,000 to produce.

Tantalum[17,19]: Baughman and Taylor of Fansteel Metallurgical Corp.

reported on the preparation of tantalum metal by selective solution[22]. Commercial potassium fluotantalate is reduced with molten aluminum to produce $TaAl_3$. The aluminum then is removed with molten copper. The resulting tantalum powder is mixed with copper, and by powder metallurgy, made into good bars, sheet, and foil.

Torti[23] reported work on the purification of commercial tantalum powder by a single, vacuum, consumable-arc melting operation. Ingots of considerably higher purity than the original powder were obtained. The effect of carbon addition to an oxygen-rich starting material was investigated, and the optimum C:O ratio for maximum refinement was located, approximately. Under favorable conditions, the oxygen content was reduced by approximately one order of magnitude.

Klopp, et al[24] of Battelle reported on the purification of commercial-purity tantalum powder by vacuum sintering in the temperature range of 2600° to 2860°C. Mixtures of TaC and Ta_2O_5 and tantalum powder containing intentional oxygen, carbon, and nitrogen additions also were studied. The mechanism for removal of each impurity, and the conditions necessary for preparing ductile tantalum by vacuum sintering were discussed.

Substantial price reduction of high-purity tantalum is expected for a new process developed by Aries Associates[25]. The process is reported to bypass the conventional fluoride reduction and purification processes and to produce a high-purity halide that can be reduced directly by electrolysis or a Kroll-type system. First plant to use the process has been built in Japan. Aries believes the process will be applicable to other refractory metals.

Tungsten: Tietz, in this column (November 1959), reviewed current research on tungsten, with emphasis on the metallurgical properties. It was reported that the US Bureau of Mines has five stations actively engaged in research programs directed toward production and evaluation of high-purity tungsten.

Zadra[26] comprehensively summarized milling practices and chemical treatment methods (including flowsheets) used at most of the major and at a number of smaller domestic tungsten operations. Production and uses of tungsten metal and analytical methods also were discussed.

Nieberlein and Kenworthy[27] of the US Bureau of Mines have made tungsten metal in massive form on a laboratory-scale by hydrogen reduction of tungsten hexafluoride at 600°C. Metal made in this manner had a purity of 99.99 pct or better, with reference to all detectable impurities, including gases. Tolerance for a wide variation in operating conditions was reported. Efficiency of the process varied from 91 to 97 pct, based on the quantity of WF_6 consumed.

Zadra and Gomes[28] of the US Bureau of Mines produced 99.7-99.9 pct tungsten metal by electrolysis of scheelite ($CaWO_4$). In the process, scheelite is dissolved in a fused alkali, phosphate, or borate bath with sodium chloride added to flux the CaO and increase fluidity. Optimum bath temperature varies from 1740° to 1920°F, and current density ranges from 9 to 53 amp per sq ft. Power consumption averages 1 to 2 kw-hr per lb of tungsten produced.

The US Bureau of Mines station at Albany, Ore., recently reported on the preparation of *soft* tungsten by bomb reduction of tungstic oxide with calcium. Enough heat was produced in the reaction to melt the tungsten that was formed. The crystal size was reported to be many times smaller than crystals produced by arc melting. The metal, which was almost pure tungsten, was hammer forged at 900°C to 70 pct of its original thickness. When it was remelted by standard methods, the *soft* tungsten converted to ordinary tungsten.

A flowsheet for the Union Carbide Nuclear Co. process for producing molybdenite and copper concentrates, molybdenum trioxide, calcium tungstate, and high-purity ammonium paratungstate was published recently [29]. It is reported that the process includes a solvent extraction step, and is the first process to prepare a pure tungstate directly from scheelite ore.

Vanadium: Five US Bureau of Mines experimental stations and laboratories were scheduled to do research on vanadium during 1960. Studies planned include: 1) preparation of vanadium compounds for reduction to high-purity metal, 2) electrorefining in fused-salt baths to produce high-purity metal, and 3) effects of impurities on the properties of the metal and its alloys.

Merrill[30], in his paper on ductile vanadium, reviewed the extractive metallurgy of vanadium from the ore to high-purity metal.

Yttrium: General Eectric Co. personnel reported on the properties, fabrication, and potential uses of yttrium[31]. Although yttrium is not a refractory metal, its use as an alloying agent is indicated for high-temperature applications in atomic power plants and aircraft. Three US Bureau of Mines reports describe research on the extractive metallurgy of yttrium and rare-earth elements from euxenite[32]. High-purity yttrium is made commercially by reducing high-purity yttrium fluoride or chloride with purified lithium or calcium. Research quantities of highly purified yttrium have been made by starting with relatively pure metal and then using vacuum distillation or solid-state electrolysis.

* Bureau of Aeronautics and Bureau of Ordnance combined to form the Bureau of Naval Weapons.

References

[1] L. W. Coffer: Atomic-Age Metal Extraction, *Chemical Engineering*, Jan. 27, 1958, pp. 107-122.

[2] *Engineering and Mining Journal*, February, 1960, pp. 89-158.

[3] Report of Com. on Ref. Met. of Mat. Ad. Bd., Div. of Eng. and Ind. Resources, National Research Council, Washington, June, 1959.

[4] R. I. Jaffee: Refractory Metals, chapter Proceeding of an Intern. Symp. of High Temp. Tech., *McGraw-Hill Book Co.*, 1960.

[5] C. A. Hampel: Rare Metals, *Chemistry in Canada*, November, 1959, pp. 77-82.

[6] B. W. Gonser: Industry of the Newer Metals; Progress in the USA, summarized in *Battelle Technical Review*, December, 1958, pp. 9-14.

[7] J. W. Franklin: Electrons and Ions . . . Keys to Mineral Processing, *Engineering and Mining Journal*, April, 1958, pp. 85-100.

[8] E. M. Sherwood: Less Common Metals, *Industrial Engineering Chemistry*, September, 1959, pp. 1190-1196.

[9] C. W. Dannatt: Fifty Years of Extractive Metallurgy, *Mining Magazine*, January, 1960.

[10] D. F. Othmer: Fluidization, *Reinhold Publishing Corp.*, 1956.

[11] M. Leva: Fluidization, *McGraw-Hill Book Co.*, 1959.

[12] D. W. Hopkins: Physical Chemistry and Metal Extraction, *Macmillan Co.*, 1955.

[13] J. Newton: Extractive Metallurgy, *John Wiley and Sons*, 1959.

[14] Electron Beams Break into Production, *Chemical Engineering*, July, 1959, p. 80.

[15] R. G. Bourdeau: Research on the Production of Ultra Pure Refractory Metals, Final Summary Report, Navy contract No. 58-471-c, May 15, 1959.

[16] Iochrome, Bulletin No. 30, Chromalloy Corp.

[17] R. A. Labine: Wanted, Better Refractory Alloys, *Chemical Engineering*, November 30, 1959, p. 36.

[18] J. Sandor: Niobium (Columbium)—Its Future Prospects, *Metallurgia*, April, 1959, pp. 185-194.

[19] G. L. Miller: Tantalum and Niobium, *Academic Press Inc.*, 1959.

[20] Colorado Columbium Deposits Held by DuPont, *Engineering and Mining Journal*, February, 1960, p. 200.

[21] C. T. Sims: Availability of Niobium (Columbium), KAPL-M-CTS-1, March 8, 1960.

[22] B. N. Chakravarti and A. T. Prince: The Chlorination of Columbium Ores and Concentrates, (Reactive Metals, The Metallurgical Society Conferences), *Interscience Publishers Inc.*, 1959, pp. 349-375.

[23] R. F. Rolsten: A Study of the Iodide Niobium Process, *Journal of Electrochem. Society*, November, 1959, pp. 975-980.

[24] D. S. Fairgrieve and J. W. Fortner: Production and Purification of High-Purity Hafnium, reviewed by R. G. Jones, JOURNAL OF METALS, January, 1960, p. 25.

[25] Fall Meeting: Molybdenum and Tantalum Processes: JOURNAL OF METALS, February, 1960, p. 160.

[26] I. E. Campbell, D. M. Rosenbaum, and B. W. Gonser: The Availability, Recovery, and Properties of Rhenium Metal, *J. of the Less-Common Metals*, June, 1959, pp. 185-191.

[27] M. L. Torti: Purification of Tantalum Obtained by Vacuum Arc Melting, *Electrochemical Society Journal*, January, 1960, pp. 33-35.

[28] *Product Engineering*, Sept. 28, 1959, p. 23.

[29] J. B. Zadra: Milling and Processing Tungsten, *US Bureau of Mines* Information Circular 7912, 1959.

[30] V. A. Nieberlein and H. Kenworthy: High Purity Tungsten by Fluoride Reduction, *US Bureau of Mines* R.I. 5539, 1959.

[31] J. B. Zadra and J. M. Gomes, Electrowinning Tungsten and Associated Molybdenum from Scheelite, *US Bureau of Mines* R.I. 5554, 1959.

[32] Soft Tungsten Mystifies, *Chemical and Engineering News*, Jan. 4, 1960, p. 40.

[33] Union Carbide Changes Bishop Process, *Engineering and Mining Journal*, October, 1959, p. 103.

[34] G. E. Pushes Yttrium: *Chemical and Engineering News*, Nov. 16, 1959, p. 42.

[35] *US Bureau of Mines* Reports of Investigation 5521, 5531, 5544, 1959.

[36] T. W. Merrill: Ductile Vanadium, A New Engineering Material, JOURNAL OF METALS, September, 1958, pp. 618-621.

[37] W. D. Klopp, D. J. Maykuth, H. R. Ogden, and R. I. Jaffee: Purification Reactions of Tantalum During Vacuum Sintering, (presented at the Fall Meeting, of The Metallurgical Society, 1959); to be published in *AIME Trans.*

AIME STAFF:
SECRETARY—ERNEST KIRKENDALL
ASST. SECRETARIES—J. B. ALFORD, H. N. APPLETON, J. C. FOX, R. W. SHEARMAN
ASST. TREASURER—JOHN LYNCH
METALLURGICAL SOCIETY STAFF:
SECRETARY—R. W. SHEARMAN
ASST. SECRETARY—D. C. JOHNSTON

NEWS OF YOUR PROFESSION

Division Officers for 1961 Nominated by Metallurgical Society

The Nominating Committees of the Iron and Steel Division, Extractive Metallurgy Division, and Institute of Metals Division have submitted their nominees for officers and Executive Committee members to serve in 1961.

ISD

Iron and Steel Division nominees, to begin service in February 1961, following the AIME Annual Meeting are: Chairman, Gerhard Derge, Carnegie Institute of Technology; Chairman-Elect, B. M. Larsen, U.S. Steel Corp.; Executive Committee members (1961-1964), R. D. Hindson, Steel Co. of Canada, and D. R. Loughrey, Jones & Laughlin Steel Corp.; Executive Committee members (1961-1963), T. F. Olt, Armco Steel Corp., and J. F. Elliott, Massachusetts Institute of Technology.

EMD

The Extractive Metallurgy Division nominees are: Chairman, Richard C. Cole, Vitro Chemical Corp. of America; Chairman-Elect, W. R. Opie, National Lead Co.; Secretary, R. W. Shearman; Treasurer, T. D. Jones, American Smelting & Refining Co. Executive Committee Officers (1961-1963): T. I. Moore, American Zinc Co. of Illinois; and H. W. St. Clair, US Bureau of Mines.

IMD

The Institute of Metals Division nominees are as follows: Chairman, J. H. Jackson, Battelle Memorial Institute; Senior Vice Chairman, David Swan, Linde Co.; Vice Chairman, Raymond L. Smith, Michigan College of Mining and Technology; Secretary-Treasurer, D. C. Johnston. Those to serve on the Executive Committee for three-year terms are: W. A. Backofen, Massachusetts Institute of Technology; Julius J. Harwood, Office of Naval Research; and F. L. Vogel, Jr., Radio Corp. of America.

Nominate Karl L. Fetters as 1961 President-Elect of The Metallurgical Society

Karl L. Fetters has been nominated Vice President and President-Elect of The Metallurgical Society for a one-year term, beginning February 1961, according to W. A. Dean, Chairman of The Metallurgical Society's Nominating Committee. Dr. Fetters automatically becomes President of the Society in 1962.

The Society President-Elect is vice president of research and development, The Youngstown Sheet and Tube Co. His biography appears under **Directors**, p. 579.

The ISD's nominees also include Gerhard Derge (for a one-year term as ISD Chairman beginning February 1961) and Harold B. Emerick, Director of The Metallurgical Society for a three-year term beginning in 1961. Mr. Emerick is already on the Society's Board, his current term expiring in 1961, however.

Dr. Derge is professor of metallurgy, Carnegie Institute of Technology, and is editor of TRANSACTIONS OF THE METALLURGICAL SOCIETY OF AIME. He will also serve on the Society Board for one year.

Mr. Emerick is director of technical services for Jones & Laughlin Steel Corp.

Nominations to the Nominating Committee of The Metallurgical Society from the ISD are: B. R. Queneau, U.S. Steel Corp. (1961-1962); and T. D. Hess, Youngstown Sheet & Tube Co. (1961-1963).

The Extractive Metallurgy Division has proposed the following nominees: Richard C. Cole, Vitro Corp. of America, 1961 Chairman; and A. E. Lee, Jr., Director of The Metallurgical Society for a three-year term beginning February 1961. Mr. Cole is vice president in charge of manufacturing for Vitro Chemical Co. and a vice president of Vitro Minerals Corp. Mr. Lee is technical director of the Amco div., American Metal-Climax, Inc. Mr. Cole will serve a one-year term as Director of The Metallurgical Society coincident with his chairmanship of the EMD.

K. L. FETTERS

Nominees to the Society Nominating Committee from the EMD for a one-year term beginning February 1961 are: A. E. Lee, Jr., American Metal-Climax, Inc.; Bruce Gonser, Battelle Memorial Institute; and H. W. St. Clair, US Bureau of Mines.

The Institute of Metals Division's nominees are J. H. Jackson for 1961 Chairman, and W. J. Harris, Jr., Director of The Metallurgical Society for a three-year term. Mr. Jackson also will serve on the Board for a one-year term coincident with his chairmanship. He is manager of the Department of Metallurgy, Battelle Memorial Institute. Dr. Harris is executive director of the Materials Advisory Board, National Academy of Sciences-National Research Council.

Named to the Society Nominating Committee from IMD for one-year terms, beginning in February 1961, are: C. S. Barrett, University of Chicago; W. R. Hibbard, Jr., General Electric Co.; and T. A. Read, University of Illinois.

For AIME nominations, turn the page.

Announce Nominations for AIME's 1961 Officers

The Chairmen of the three Society Nominating Committees have announced nominations for AIME President-Elect, Vice Presidents, and Directors for 1961.

Each of the Society's Bylaws provides for additional nominations. (The Bylaws of each Society in substantially final form have been published in the Journals and in revised form in the 1957 Institute Directory). If no alternate slate is proposed, no letter ballot will be necessary and the selections of the three Nominating Committees will be declared elected, in accordance with the respective Society Bylaws, well in advance of their installation at the 1961 Annual Meeting in February in St. Louis.

L. E. ELKINS

Lloyd E. Elkins has been nominated to serve as AIME President-Elect, assuming the presidency in 1962. Nominated by the Society of Petroleum Engineers, Mr. Elkins will hold the office of AIME President-Elect in 1961.

Mr. Elkins is production research director for Pan American Petroleum Corp., Tulsa, Okla. He has been employed by Pan American since his 1934 graduation from the Colorado School of Mines, starting as a roustabout and assuming his present position in 1949. An active AIME member since 1938, Mr. Elkins offices have been too numerous to list here. Most recently, he was chairman of the Committeee to Study Financial Assistance to Subsections and the Swan Report. He is currently Chairman of the AIME Member's Gift Campaign for the United Engineering Building.

Vice Presidents

Carleton C. Long, director of research, zinc smelting div., St. Joseph Lead Co., has been nominated to serve a one-year term as Vice President of the AIME. Dr. Long is the 1960 President of The Metallurgical Society and is also a Director of the AIME. A member of the AIME since

C. C. LONG

1937, he has long been active in Institute activities. Dr. Long was Chairman of the Lead-Zinc Committee in 1948 . . . one of the founders of the EMD and its Chairman in 1950 . . . Chairman of the Metals Branch Council (1951) . . . AIME Director (1954-1957), (1959-1962) . . . *and* Chairman of the Douglas Award Committee in 1956.

Dr. Long joined St. Joseph Lead Co. just after receiving his doctorate from the University of Colorado in 1935. His first assignment was as a research engineer with the Josephtown smelter of the zinc smelting div., Monaca, Pa. He was made director of the plant research dept. at Josephtown in 1937, and from here assumed his present position.

John S. Smart, Jr. is the second representative of The Metallurgical Society serving as an AIME Vice President. Mr. Smart is currently Vice President and President-Elect of The Metallugrical Society, and automatically becomes the Society President in 1961. He is also a Director on the AIME Board.

Mr. Smart joined the American Smelting & Refining Co. in 1936 as a research metallurgist. He next became supt. of copper development, asst. to the vice president and director of research, asst. director of research, and now his current position as general sales manager. Mr. Smart's research interests have included the preparation and properties of high-purity copper . . . effects of impurity additions . . . and the development of continuous casting processes for bronzes and commercial types of copper.

J. S. SMART, JR.

Mr. Smart's AIME activities include the 1954 chairmanship of the Rossiter W. Raymond Award Committee. He was on the receiving end of the IMD Award in 1948, now called the Mathewson Gold Medal. In 1955, he was the Annual Lecturer. of the Australian Istitute of Metals.

Arthur B. Cummins, President of the Society of Mining Engineers for 1960, has been nominated for the post of AIME Vice President for a one-year term beginning February 1961.

Professionally, Dr. Cummins is manager of the Central Chemical and Physical Research dept., Johns-Manville Research Center. Recognized internationally as an authority in mining asbestos, mineralogy, and filtration, Dr. Cummins holds 17 patents.

He has been an active AIME member since 1936, serving on and heading various mining society committees.

A. B. CUMMINS

Jerome W. Woomer, Past-President of the Socety of Mining Engineers, is its second nominee for AIME Vice President. His term will also be one year.

Mr. Woomer has his own consulting firm—J. W. Woomer & Associates—but his career has reached all levels of the mining industry, from day laborer to mine manager.

Long a member of the Society of Mining Engineers' Coal Division, Mr. Woomer was its 1958 Chairman. He is also active in several other mining societies.

J. W. WOOMER

Wayne E. Glenn, the 1960 President of the Society of Petroleum Engineers, is a vice presidential candidate from the Society of Petroleum Engineers. His term begins February 1961.

Professionally, he is production manager for Continental Oil Co., which he joined in 1939.

His service to the Petroleum Society includes the posts of Chairman, director, and section delegate for the Pacific Petroleum Chapter; director of the Denver Petroleum section; and member of the SPE Board of Directors (1957-1958).

John S. Bell, production manager of the Gulf Coast div., Humble Oil & Refining Co., is the second vice presidential candidate from the Society of Petroleum Engineers. He was the 1959 President of the Society, and was previously Chairman of the Society's Production Engineering Committee (1953-1955). He has been a member of the Council of the Pacific Petroleum Chapter . . . Chairman of the AIME Nominating Committee . . . and is now Chairman of the SPE Nominating Committee.

Mr. Bell has been with the Humble company since 1933, soon after receiving his B.S. in petroleum engineering from the University of Oklahoma.

Directors

Karl L. Fetters, in addition to being nominated Vice President and President-Elect of The Metallurgical Society, begins a three-year term as an AIME Director in February 1961.

Dr. Fetters was the 1958 Chairman of the Iron and Steel Division; he was also Chairman of the Division's Nominating Committee in 1959. A member of the AIME since 1937, his professional career began in 1933 with the National Tube Co. He was with the Youngstown Sheet and Tube Co. from 1936-1938, then returned to school, receiving his Ph.D. from Massachusetts Institute of Technology in 1940. He went back to Youngstown Sheet and Tube for a year, then taught at Carnegie Institute of Technology for two years before resuming his association with Youngstown Sheet.

R. C. COLE

Richard C. Cole is the second member of The Metallurgical Society to be nominated to the AIME's Board of Directors for a three-year term. Mr. Cole is vice president in charge of manufacturing for Vitro Chemical Co. and a vice president of Vitro Minerals Corp. He was with the American Smelting & Refining Co. for 20 years before joining Vitro. When he joined the Corp. in 1954, Mr. Cole was named manager of the Vitro Uranium Co.'s processing plant in Salt Lake City. He was made vice president of Vitro Uranium in 1957, and president in 1959. When Vitro Uranium in 1959 became part of the newly-formed Vitro Chemical Co., he became vice president of the new firm.

C. L. WILSON

Clark L. Wilson, who will begin a three-year term as AIME Director from the Society of Mining Engineers next February, is Chairman of the Emergency Lead-Zinc Committee headquartered in Washington, D.C. The Committee represents the interests of more than 100 companies engaged in lead and zinc mining in the US.

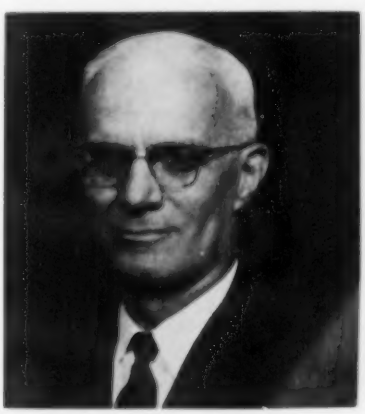
Prior to assuming his new duties, Mr. Wilson was vice president and manager of operations for the New Park Mining Co.

His AIME association dates from 1935, and in 1936 he won the Utah section's student paper award. He became the Chairman of this same Utah section in 1953. Mr. Wilson's other offices are too numerous to mention.

William B. Stephenson is the Society of Mining Engineers' second nominee for a three-year term on the AIME Board of Directors. Mr. Stephenson is also the Society's President-Elect for 1960, to assume the presidency in 1961.

W. E. GLENN

J. S. BELL



W. R. STEPHENSON

Directors . . .

(Continued from page 579)

Mr. Stephenson is president of the Allen-Sherman-Hoff Pump Co., Frazer, Pa. An active AIME member since joining in 1946, Mr. Stephenson is Past-Chairman of the Minerals Beneficiation Division. He is General Chairman of the International Symposium on Agglomeration to be held in Philadelphia April 12-14, 1961.

Robert B. Gilmore is the Society of Petroleum Engineers' nominee as AIME Director. His term will begin in February 1961. Mr. Gilmore is now senior vice president and director of DeGolyer and MacNaughton in Dallas, Tex. Prior to joining the company in 1941, he was with the Shell Oil Co.

Long active in petroleum society activities, he was Petroleum Branch Chairman in 1955 . . . Branch Treasurer in 1950 . . . Chairman of the Production Review Committee in 1953-1954 . . . Chairman of the Executive Committee in 1956 . . . and Chairman of the Nominating Committee, also in 1956. He is presently a member of the AIME Endowment Committee.

R. B. GILMORE

The second AIME Director representing the Society of Petroleum Engineers will be the 1962 President of the Society. The SPE Nominating Committee will announce his name in the fall and he will become an AIME Director, starting a three-year term in February 1961.

In addition to the incoming officers and directors listed on the preceeding pages, the following individuals now on the Board will serve in these capacities after the Annual Meeting in February 1961:

President of the AIME for 1961, Ronald R. MacNaughton.

Past-President for 1961, Joseph L. Gillson.

AIME Directors for 1961, J. B. Austin, and John Chipman, The Metallurgical Society; R. H. Felerabend and J. C. Gray, Society of Mining Engineers; and H. F. Beardmore and E. M. Kipp, Society of Petroleum Engineers.

AROUND THE SECTIONS

Lehigh Valley section's Executive Committee met prior to the Section's Annual Spring Dinner-Meeting April 15th. The Hotel Bethlehem meeting in Bethlehem, Pa., brought out the fact that the Section has surpassed its United Engineering Center goal by $1453. The goal was $3100; at meeting time $4553 had been collected from 44.03 pct of the membership, or an average of $38.58 per member. Congratulations!

The Section's annual Dinner-Dance was held May 27th at the Berkshire Country Club, Reading, Pa. R. W. Sleeman, section chairman, presided over the evening's festivities attended by 122 members, ladies, and guests. The Section will next meet in September, and a field trip to the Grace Mine of Bethlehem Cornwall Corp., Morgantown, Pa., is first on the schedule.

Chicago section's Annual President's Night Dinner Dance was graced by the presence of Joseph L. Gillson and his wife Gracie. The Gillsons received the Section members and their wives prior to dinner and dancing at the South Shore Country Club May 7th.

St. Louis section had as its President's Night speaker R. R. McNaughton, President-Elect of AIME. Mr. McNaughton, manager of the Metallurgical div., Consolidated Mining & Smelting Co. of Canada Ltd., spoke on *Canada and Canadians*. The May 13th dinner-meeting was held at Le-Chateau in St. Louis.

San Francisco section on May 18th viewed *Toquepala Target*, a film depicting the large porphyry copper deposit in southern Peru managed by the American Smelting & Refining Co., and in which Cerro de Pasco, Phelps Dodge, and Newmont are participants.

Arizona smelting div. technical subdivision of the Arizona section, met on May 7th in Superior, Ariz. A total of 60 persons turned out for the three-speaker program. E. J. Caldwell, Magma Copper Co., spoke on *Magma's Suspended Arch*. L. P. Klein, Phelps Dodge Corp., talked on *Gaseous Refining of Blister Copper*, while J. H. Davis, also of Phelps Dodge, described *Reformer Automation in Connection with Gaseous Refining of Blister Copper*.

New York section's Physical Metallurgy Group listened to F. D. Rosi, Radio Corp. of America, during its May 17th meeting. Dr. Rosi spoke on *Some Aspects of Semiconductor Metallurgy*, giving a comprehensive account of the present state of the art. The audience of 40 heard a discussion of the properties which influence semiconductor performance, such as chemical purity . . . structural perfection . . . controlled addition of impurities . . . and thermoelectricity.

E. P. Reed, Southeast section chairman (right) has a word with featured speaker, D. G. MacDonald.

Southeast section met in the Thomas Jefferson Hotel in Birmingham on April 28th to hear Donald G. MacDonald, Southern district manager, E. I. du Pont de Nemours & Co.'s extension division.

Speaking on the topic *From Research to Reality*, Mr. MacDonald pointed out that "Every new discovery raises the haunting question: 'Is this really good for something, or is it simply a scientific curiosity?' Each new discovery requires enormous amounts of effort, time, and money in trying to determine what it might be good for. Each must be examined and evaluated by scores of competent people with rich and varied backgrounds and projected into a thousand unsolved problem situations to see whether or not it helps in the solution of any of the world's problems."

Alluding to industrial size, Mr. MacDonald said, "Each unit must be big enough to serve society well in the performance of its chosen function. The size of a business, like the length of a bridge, is determined by the job it is attempting to do." . . .

"As I survey the tasks ahead, my fear is not that individual and corporate effort will be found too big, but that history may prove them too little!"

Hudson-Mohawk section's May 5th meeting offered a talk on *Motion of Atoms in Metals During Radiation*

Bombardment. Speaking was John B. Gibson of Brookhaven National Laboratory. Dr. Gibson described the use of a computer to solve equations of atom motion in a crystal undergoing radiation damage.

During the business portion of the meeting, Section chairman Arthur A. Burr conferred a membership pin on John Newkirk of General Electric Research Laboratory. The award was in token of his recruiting five new members for the Society. Chairman Burr also took the occasion to emphasize the need to contribute to the United Engineering Center Building Fund Campaign.

Section officers for the 1960-1961 meeting season also were elected. They are as follows: J. J. Gilman, Chairman; Wiley Childs, Vice Chairman; Jack Keverian, Secretary; Paul Methe, Treasurer; J. H. Keeler, Section Delegate; Wiley Childs, Program Chairman. The five men also constitute the Executive Committee.

Cleveland section's last meeting of the 1959-1960 season was devoted to *Dislocations and Plasticity*. Speaking was J. J. Gilman, General Electric Research Laboratory. Technical Chairman for the May 19th meeting was John Pugh of GE's Lamp div.

Western section, NOHC, had its last meeting before the summer lull on May 25th. The dinner-meeting was addressed by N. L. Bock, chief engineer of Bethlehem Steel Co.'s Seattle works. He spoke on *Modernization of the Seattle Works*.

New York section invited its members to tour the U. S. Metals Refining Co.'s Carteret, N. J., plant on May 20th. After a delicious buffet luncheon given by the hosts, the guests were escorted around the plant, which produces copper from ore, scrap, and concentrates. During the 2-hr trip the visitors saw the smelting section with the reverberatory and cupola furnaces and the converters. In the tough pitch dept., they were shown the anode and wire bar furnaces, together with the wire bar and continuous billet casting operations. Among the new installations the bag house and scrap bailer were viewed with interest. A quick look at the tank house and the electrolytic copper powder production completed the educational tour.

Black Hills section had a record-breaking turnout for its April 7th meeting at Moosecamp Lodge in Black Hills, S. D. A total of 123 members, wives, and invited students of the South Dakota School of Mines and Technology heard AIME President Joseph L. Gillson speak on the pre-Columbian ruins of Mexico.

Also on hand were Clifford J. Hicks, AIME's Western Field Representative; Ernest Kirkendall, AIME Secretary; and Dr. and Mrs. Guy Bjorge of San Francisco. Professor Edwin H. Oshier served as Chairman for the meeting in the absence of Frank Howell.

Ohio Valley section took a field trip through Armco Steel Corp.'s East works in Middletown, Ohio, May 13th. The tour was prefaced by a luncheon courtesy of Armco. Following the tour, the group gathered at the Sports Bowl for a social hour and dinner-meeting. On the heels of dinner came a short business meeting, then the evening's featured talk. Speaking was Harry Holiday, Jr., asst. general superintendent, at the East works. Mr. Holiday, winner of this year's Iron and Steel Division J. E. Johnson, Jr. Award, spoke on *Steel Plant Operations*.

On June 9th Section members joined with the Women's Auxiliary of AIME at the Shelter House in Columbus. The Dinner-Meeting featured a talk by Prof. H. E. Phillian of The Ohio State University. His subject was *Hawaii, Our 50th State*. The talk was accompanied by color slides.

Carolinas section is the most recent addition to the AIME fold. The members have broken from the Southeast section in order to strengthen their professional and geographical ties. Composed of both members in North and South Carolina, the Section reflects a technical interest in non-metallic or industrial minerals. The Section is No. 92 of AIME.

For maximum efficiency in the production of specimens in the metallurgical laboratory the Buehler cabinet type polishing table with companion storage cabinets represents the latest modern development of this type of equipment.

The convenience of this streamlined polishing equipment saves time and encourages the operator to produce the highest quality of polished sample.

Item No. 1511 is a two-unit polishing table with Formica top approximately 60" long x 27" deep by 30" high to table top. Two 12" swing spouts, drain, 8" diameter wash bowl plumbing and wiring.

Recommended accessories to complete an efficient set up for maximum convenience are: No. 1512 storage cabinet with recessed light and No. 1513 supporting panel for installation above polishing desk. Or, No. 1514 floor model storage cabinet. Both these cabinets can be used together to advantage in most laboratories.

The Formica top and back on the table and cabinet is installed with a smooth Formica edge that eliminates all metal rims that may form pockets for water and dirt. Covers are held in place on the back by magnetic holders. The large 8" wash bowl is a new feature that enables the operator to use both hands in washing specimens.

All metal construction finished in hammer tone grey makes a very attractive appearance. Prompt delivery can be made on these new items.

The Buehler Line of Specimen Preparation Equipment Includes . . . Cut-Off Machines • Specimen Mount Presses • Power Grinders • Emery Paper Grinders • Hand Grinders • Belt Surfacers • Mechanical and Electro Polishers • Polishing Cloths • Polishing Abrasives

Buehler Ltd. METALLURGICAL APPARATUS
2120 Greenwood Avenue, Evanston, Illinois

Deformation Meeting at Estes Park, Colo. July 11-12

The conference on Response of Metals to High-Velocity Deformation will be held July 11-12 at the Stanley Hotel, Estes Park, Colo.

The two-day meeting will incorporate 16 technical papers, plus a full slate of social activities. The crystallographic, metallographic, and basic metallurgical phenomena that occur in metals under high strain rate will be the basis for this meeting. It will not be concerned with explosive forming methods or engineering.

Advance registration is $15 for AIME members; $20 for non-members. Make checks payable to **W. C. Leslie, Treasurer,** c/o Dr. W. C. Leslie, E. C. Bain Laboratory for Fundamental Research, U. S. Steel Corp., Monroeville, Pa.

Hotel registrations should be made directly to the Manager, Stanley Hotel, Estes Park, Colo.

USE the SERVICES of THE ENGINEERING SOCIETIES LIBRARY

29 West 39 Street,
New York 18, N. Y.

NEW STUDENT MEMBERS

University of California
Haley, William M. E.

Case Institute of Technology
Gould, George C.

Colorado School of Mines
Dugger, Albert L.
Halbe, Douglas N.
Harbur, Delbert R.
Hasse, Glen E.
Heister, Samuel B.

University of Illinois
Wittman, Henry R.

Massachusetts Institute of Technology
Reed, Milton D.

University of Michigan
Maniar, Gunvant N.
Oesman, Oedjo

University of Minnesota
Wang, Chun Tsin

Ohio State University
Cox, Joseph D.

Pennsylvania State University
Clupper, Jerry L.

Rensselaer Polytechnic Institute
Guleserian, Edward N.
Pratt, Joel S.

South Dakota School of Mines & Tech.
Hydinger, Kenneth D.

Texas Western College
Verdes, Cesar

University of Utah
Anderson, Robert J.

Wayne State University
Allen, Donald L.
Mackenzie, John C.

STUDENT NEWS

The Student News page has been suspended for the summer recess. The feature will reappear in the fall, and we hope that you will keep us informed on your activities. Special thanks go to the student chapter secretaries, chairmen, and faculty advisors who made this feature possible. Keep up the good work in the fall!

Call for Titanium Papers for Session During Annual Meeting

There will be a half-day session devoted to titanium research during the 1961 AIME Annual Meeting in February, according to H. J. Middendorp, Chairman of the subcommittee making the preparations.

Prospective authors are asked to submit abstracts of papers as soon as possible, and completed papers should be ready by Sept. 30. Those interested in presenting papers should contact: *H. J. Middendorp, Chief, High Strength Metals Section, Wright Air Development Division, Wright-Patterson Air Force Base, Ohio.*

Change of Address

▼To be sure that you receive your publications and correspondence promptly, please fill in the form below and send it to **The Metallurgical Society of AIME,** 29 W. 39th St., New York 18, N.Y.

Name _____

Old Mailing Address _____

_____

_____

New Mailing Address _____

_____

_____

Personals Form

▼**Personals:** Please list below your former company and title and your new title and company (or new work) for use in JOURNAL OF METALS. (Copy deadline for personals items is six weeks before date of issue.)

Former Company _____

Former Title _____ Length of Time There _____

New Company _____

New Company Address _____ Date of Change _____

New Title _____

Any recent activity that would be of interest to members:

_____

_____

_____

PROPOSAL FOR AIME MEMBERSHIP

I consider the following person to be qualified for membership and request that a membership kit be mailed to him:

Name of Prospective Member:

_____

Address

_____

_____

_____

Name of AIME Member:

_____

Address

_____

_____

_____

JM

MEMBERSHIP

Proposed for Membership
Metallurgical Society of AIME

Total AIME members on May 31, 1960, was 33,606; in addition 2,449 Student Members were enrolled.

ADMISSIONS COMMITTEE

L. L. Seigle, Chairman; W. L. Brytczuk; F. B. Foley; T. D. Jones; Harold Margolin; Shadburn Marshall.

The Institute desires to extend its privileges to every person to whom it can be of service, but does not desire as members persons who are unqualified. Institute members are urged to review this list as soon as possible and immediately to inform the Secretary's office if names of people are found who are known to be unqualified for AIME membership.

Members

Allan, Douglas H. W., New York, N. Y.
Belcher, George W., Chicago, Ill.
Bradbury, Terrence C., Hamilton, Ontario, Canada
Burch, Charles J., Fairless Hills, Pa.
Conn, Ross E., Youngstown, Ohio
Edgecombe, David A., Beaver Falls, Pa.
Fenoulhet, B. L., Montreal, Quebec, Canada
Fischley, Burton J., Dearborn, Mich.
Green, Charles P., Belleville, Ill.
Harmon, Vernon L., Carnegie, Pa.
Harp, Doyle A., Pittsburgh, Pa.
Hoppin, George S., III, Cincinnati, Ohio
Hoskins, John A., Wheeling, W. Va.
Kesler, George H., Weirton, W. Va.
Masoner, Charles R., El Paso, Texas
McCarthy, Justin J., Coah, Mexico
Middendorp, Howard J., Dayton, Ohio
Offutt, J. J., Mexico, Mo.
Penny, Stephen, Fairfield, Ala.
Quinn, Charles C., Chicago, Ill.
Porco, Daniel A., Jr., Pittsburgh, Pa.
Randolph, Halfred F., Mexico, Mo.
Recoder, Roberto F., Buenos Aires, Argentina
Salgado, Manuel, Talachuano, Chile
Smail, Richard F., Pittsburgh, Pa.
Snyder, Milton H., Chicago, Ill.
Southey, Thomas W., Islington, Ont., Canada
Stevens, Robert P., Chicago, Ill.
Strobel, Herman R., Reading, Pa.
Swaminathan, Kandamangalan, Pittsburgh, Pa.
Tuepker, Ralph A., Chicago Heights, Ill.
Willis, Arthur C., Dallas, Texas.
Wooding, P. J., Pittsburgh, Pa.

Associate Members

Bayley, Glen F., Chicago, Ill.
Behner, Donald C., Parma Heights, Ohio
Brown, Robert C., Nashville, Tenn.
Campbell, John L., Lima, Ohio
Coryell, George R., Dolton, Ill.
Haniford, Norbert N., Hammond, Ind.
Heatley, S. M., St. Louis, Mo.
Ledbetter, Reid, Dearborn, Mich.
McKaig, J. A., New York, N. Y.
Narayanan, Thirunoneoil K., Pittsburgh, Pa.
Palma, Jose A., Caracas, Venezuela
Rosenquist, Robert W., New York, N. Y.
Story, William S., Washington, D. C.
Truelsen, Roger E., Croton-on-Hudson, N. Y.

Junior Members

Agarwal, Gopal P., Pittsburgh, Pa.
Swaney, N. K. Anantha, Stuttgart, Germany
Baty, Henry G., Moab, Utah
Cook, Ted H., Chicago, Ill.
Cookson, Donald H., Brackenridge, Pa.
Cosgarea, Andrew, Jr., Norman, Oklahoma
Folweiler, Robert C., Schenectady, N. Y.
Gottschall, Robert J., Mount Vernon, N. Y.
Heller, Frederick, London, England
Hendry, George A., Huntington, N. Y.
Kaplan, Samuel M., E. Chicago, Ind.
Owen, Mervin, Trail, B.C., Canada
Quigley, John J., Highland, Ind.
Spirko, Edward J., Chicago Ill.

RE-ELECTION—MEMBER

Hammond, Joseph P., Knoxville, Tenn.

REINSTATEMENT—JUNIOR MEMBER

Koo, Ronald C., Bloomfield, N. J.

REINSTATEMENT—CHANGE OF STATUS

Junior to Member

Kopchak, Michael C., Chicago, Ill.

Student to Member

Bauscher, John A., Pittsburgh, Pa.
Rieckhoff, Garman, Olean, N. Y.

Student to Junior

Perrin, James S., Superior, Wisc.

SPECIAL REINSTATEMENT—ASSOCIATE

Fleitman, Albert H., Upton, N. Y.

CHANGE OF STATUS

Junior to Member

Shaw, Donald H., Indianapolis, Ind.

Associate to Member

Daugherty, T. Stevens, Richmond, Va.
Eidam, Robert A., E. Chicago, Ind.

VERNON W. JONES

An Appreciation
by Leo F. Reinartz

Vernon Wilfred Jones, 62, died in the Middletown, Ohio, hospital on May 23rd after a prolonged cancer ailment.

Mr. Jones, an official of Armco Steel Corp., was widely known in steel circles throughout the US and Canada. He also was a prominent civic leader in his hometown.

Joining Armco in 1928, Mr. Jones became an electric furnace melter in the Central works, Middletown, Ohio. In successive promotions he became open-hearth general foreman, assistant open-hearth superintendent, and superintendent in 1943.

In 1950, he was made superintendent of steel plant production. In 1957, he was made assistant general superintendent of the Middletown works in charge of blast furnace, coke, and steel production. This was his regular assignment when he became ill.

Mr. Jones was an energetic, forward-looking, successful steel executive. He had many friends among the supervisors and workers at Armco. He was known for his fair dealings with workers.

Born in Albert Lee, Minn., on Dec. 20, 1897 Mr. Jones and his family later moved to Charleston, W. Va., where he was graduated in the public schools. He then attended West Virginia University.

Prior to his Armco connection, he had worked for Hess Steel Co.'s Naval Ordnance plant in Baltimore, Md., and The International Nickel Co. in Charleston, W. Va.

Mr. Jones had been an active member of the AIME since 1931. He served one year as Chairman of the Ohio Section of the National Open Hearth Steel Committee. In 1959, he was elected Chairman of the NOHC.

Shortly before his death, Mr. Jones was awarded a life certificate of membership in the Committee.

At Armco, he was a loyal, cooperative co-worker. In technical circles he was always willing to impart his knowledge of steelmaking to associates in other steel plants, and especially to the younger men in the steel industry. He was sincere, genial, loveable, and helpful to others—a Christian gentleman.

Vernon, as he was known to many, leaves behind the memory of a life well spent in the service to others. He will be missed by those who knew him in and outside the steel industry.

OBITUARIES

Hary Hey, a prominent figure in Australia's lead and zinc industry and an AIME member since 1927, died in Melbourne April 11th at 67. Mr. Hey was chairman and managing director of the Electrolytic Zinc Co. of Austrasia Ltd. and chairman of its parent company, EZ Industries Ltd. He joined Electrolytic Zinc in 1917 and was the company's chief metallurgist from 1927 to 1943, when he was appointed technical superintendent. In 1944 he became a director and from 1945 to 1946 was general manager. He was appointed managing director in 1947 and chairman in 1952.

An Honorary Member of the Australasian Institute of Mining and Metallurgy, Mr. Hey was Deputy President of the Fifth Empire Mining and Metallurgical Congress held in 1953.

NECROLOGY

Year Elected	Name	Date of Death
1931	Calverley, Jos. G.	Nov. 28, 1959
1917	Cook, W. Lorrain	March 30, 1960
1956	Farst, Walter K.	Unknown
1956	Hehlert, Otto	June 1959
1927	Hey, Harry	April 11, 1960
1950	Houston, Fred K.	April 13, 1960
1931	Jones, Vernon W.	May 23, 1960
1911	Macauley, R. M.	April 7, 1960
1935	McKinney, A. A.	July 1959
1944	Reynolds, B. M.	Feb. 8, 1960
1959	Wolford, Louis M.	Jan. 6, 1960
1954	Whitmer, Virgil W.	November 1959

A History of Metals

Offered AIME Members At Discount Price

A History of Metals is being offered AIME members at a 10 pct discount. This 690 pp. two-volume work is being offered by Interscience Publishers Inc. The regular price is $30; however, AIME members may obtain the set for $27. The offer is made available because of The Metallurgical Society's recent association with the publisher. Interscience is publishing a series of METALLURGICAL SOCIETY CONFERENCES, the proceedings of technical sponsored by The Metallurgical Society.

Leslie Aitchison, English consulting metallurgist, is the author of **A History of Metals.** The work traces the story of metals from prehistoric times to the present day. The set's 690 pp. contains 48 tables and 262 illustrations.

AIME members may order the two-volume work through The Metallurgical Society, 29 W. 39th St., New York 18, N.Y. Non-members should order directly from Interscience Publishers Inc., 250 Fifth Ave., New York 1, N.Y.

Coming Events

July 11-12, AIME Conference on the Response of Materials to High-Velocity Deformation, Estes Park, Colo.

Aug. 10-12, Ninth Annual Conference on Applications of X-ray Analysis, Stanley Hotel, Estes Park, Colo.

Aug. 28-Sept. 2, Eighth International Symposium on Combustion, California Institute of Technology, Pasadena, Calif.

Sept. 1, Chicago Section, NOHC, Golf Outing, Gleneagles Country Club, Chicago.

Sept. 15-16, Eighth Annual Engineering Management Conference, Morrison Hotel, Chicago.

Sept. 19-20, 58th Fall Meeting, Steel Founders' Society of America, The Homestead, Hot Springs, Va.

Sept. 23-24, Southern Ohio Section, NOHC, 24th Annual Technical Conference, Deshler, Hilton Hotel, Columbus.

Oct. 3, Chicago Section, NOHC, Fall Dinner Meeting, Phil Smidt's Restaurant, Hammond, Ind.

Oct. 5-7, Rocky Mt. Minerals Conference, Newhouse Hotel, Salt Lake City.

Oct. 12, Annual Meeting of the Cast Bronze Bearing Institute, Grove Park Inn, Asheville, N. C.

Oct. 12-13, Seventh National Symposium, American Vacuum Society, Cleveland-Sheraton Hotel, Cleveland.

Oct. 12-14, Fourth Conference on Analytical Chemistry in Nuclear Reactor Technology—First Conference on Chemistry in Nuclear Reactor Technology, Gatlinburg, Tenn.

Oct. 13-14, Southwestern Section, NOHC, Fall Meeting, Statler-Hilton Hotel, Dallas.

Oct. 13-15, 1960 Annual Meeting of the Non-Ferrous Founders' Society, Grove Park Inn, Asheville, N. C.

Oct. 17-18, Annual Convention, The Magnesium Association, Pick Carter Hotel, Cleveland.

Oct. 17-20, Fall Meeting of The Metallurgical Society of AIME, Sheraton Hotel, Philadelphia.

Oct. 17-21, Fall Meeting of the Societe Francaise de Metallurgie, Maison de la Chimie, Paris.

Oct. 23-26, Seminar on Rare Earth Research, Arrowhead Center, University of California, Los Angeles.

Oct. 28, Eastern Section, NOHC, 14th Annual Conference, Warwick Hotel, Philadelphia.

Nov. 7, Pittsburgh Section, NOHC, 15th Annual Off-the-Record Meeting, Penn-Sheraton Hotel, Pittsburgh.

Nov. 9-10, Meeting of The Chemical Market Research Association, Pittsburgh-Hilton Hotel, Pittsburgh.

Nov. 8-11, First National Die Casting Exposition and Congress, Detroit Artillery Armory, Detroit.

Jan. 18, 1961, Conference on Bar and Allied Products, sponsored by Mechanical Working Committee of The Metallurgical Society, Penn-Sheraton Hotel, Pittsburgh.

ADVERTISER'S INDEX

Air Products, Inc.	*The Aitkin-Kynett*	516-517
Allis Chalmers	*Klau-Van Pietersom-Dunlap Inc.*	518
Armour Research Foundation of Illinois Institute of Technology		*
ASEA Electric, Inc.	*Mann-Ellis, Inc.*	*
Bailey Co., Wm. M.	*Downing Industrial Adv., Inc.*	*
Basic, Incorporated	*Duffy, McClure & Wilder, Inc.*	526-527
Bell Telephone Labs.	*N. W. Ayer & Son, Inc.*	*
Buehler Ltd.	*Kretcker & Meloan, Inc.*	581
Chemical Construction Corp.	*Van Brunt & Co.*	510
Corhart Refractories Co.	*Doe-Anderson Adv. Agency*	*
Davison Chemical	*Van Sant Dugdale & Co. Inc.*	Cover III
Dravo Corp.	*Ketchum MacLeod & Grove Inc.*	508-509
Frankel Co., Inc.	*Denham & Co.*	*
General Atomic	*Barnes Chase Co.*	*
General Motors Corp.	*Campbell-Ewald Co.*	*
General Refractories Co.	*Lewis & Gilman, Inc.*	*
Great Lakes Carbon Co.	*Davis, Parsons & Strohmeier, Inc.*	*
Harbison-Walker Refractories Co.	*Downing Industrial Adv. Inc.*	504-505
Hevi-Duty Electric Co.	*Bert S. Gittins Adv. Inc.*	*
Hutton Fabricating	*Ashbey Associates, Inc.*	522
Jones & Laughlin Steel Corp.	*John Patrick Starrs, Inc.*	518
Kaiser Engineers	*L. C. Cole Co. Inc.*	507
M. W. Kellogg Co.	*Fuller & Smith & Ross Inc.*	*
Lectromelt Furnace Div. McGraw-Edison Co.	*The Griswold-Eshleman Co.*	502
Leitz, Inc., E.	*L. W. Frohlich and Company*	*
Lindsay Chemical Division American Potash & Chemical Corp.	*C. Franklin Brown, Inc.*	*
Michigan Chemical Corp.	*Aves, Shaw & Ring, Inc.*	*
John Mohr & Sons	*Fred H. Ebersold Inc.*	499
Molybdenum Corp. of America	*Smith, Taylor & Jenkins, Inc.*	*
Morgan Construction Co.	*Davis Press, Inc., The*	503
National Aero. & Space Admin.	*M. Belmont Ver Standig, Inc.*	519
Norton Co.	*James Thomas Chirurg Co.*	525
Ohio Ferro-Alloys Corp.	*Frease & Shorr Adv.*	*
Pennsylvania Engineering Co.	*Downing Industrial Adv., Inc.*	501
Philips Electronics, Instruments	*Anders Associates Adv.*	520-521
Radio Corporation of America	*Al Paul Lefton Co., Inc.*	*
Ramtite Co., The	*Leo P. Bott, Jr. Adv.*	*
Robinson Clay Product Co.	*Norman Malone Assoc., Inc.*	*
Roland Press		506
Swindell-Dressler Corp.	*Downing Industrial Advertising, Inc.*	*
Sylvania Electro Products, Inc. Chemical & Metallurgical Div.	*Kudner Agency Inc.*	Cover II
Taylor Sons Co., The Chas.	*The Keelor & Stites Co.*	*
Union Carbide Metals Co. Div. Union Carbide Corp.	*J. M. Mathes, Inc.*	513
U.S. Steel Corp. Columbia-Geneva Steel Div. Tennessee Coal & Iron Div. U.S. Steel Supply Div. U.S. Steel Export Co.	*Batten, Barton, Durstine & Osborn, Inc.*	*
Unitron Instrument Div. United Scientific Co.	*Larcom Randall Adv., Inc.*	Cover IV
Walsh Refractories Corp.	*Ralph Smith Adv. Agency*	*
Wyman-Gordon Co.	*The Davis Press, Inc.*	*

* Previous issues.

DAVISON SILICA GEL . . . Life Saver for Oxygen in Air Separation Plants. To produce tonnage oxygen from low temperature air separation plants, nothing insures safer operation and higher purity than Davison Silica Gel as an adsorbent. Where argon is produced as an important by-product, Davison Silica Gel again becomes a vital agent as an adsorbent for water vapor formed during purification. Davison Silica Gel has proved its ability to remove acetylene and hydrocarbons as well as CO_2 and moisture in operation of low temperature oxygen equipment. For further information and technical facts about the use of Davison Silica Gels in the production of liquid oxygen and argon for steel and metal production, write to Davison Chemical Division, Dept. 113, Baltimore 3, Maryland.

DEPARTMENT 113

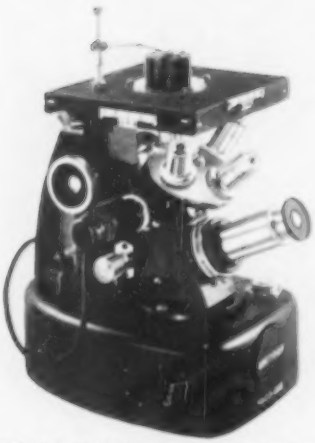
W.R. GRACE & CO.

DAVISON CHEMICAL DIVISION

BALTIMORE 3, MARYLAND

HERE ARE 25 DISCRIMINATING BUYERS WHOSE OVER 152 ORDERS AND REORDERS PROVE COMPLETE SATISFACTION WITH THESE TWO UNITRON INSTRUMENTS. AMERICAN BRASS, BATTELLE MEMORIAL INSTITUTE, CARNEGIE INSTITUTE, DOW CHEMICAL, E. I. DUPONT, GENERAL ELECTRIC, GENERAL MOTORS, GOODYEAR ATOMIC, I. B. M., MINNEAPOLIS HONEYWELL, M. I. T., MISSOURI SCHOOL OF MINES, MOTOROLA, NATIONAL BUREAU OF STANDARDS, NATIONAL CASH REGISTER, R.C.A., REYNOLDS METALS, UNION CARBIDE & CARBON, UNIV. OF COLORADO, UNIV. OF CINCINNATI, UNIV. OF WASHINGTON, UNIV. OF WISCONSIN, U.S. GOVERNMENT, U.S. STEEL, WESTINGHOUSE ELECTRIC.

These typical 25 took a total of 152



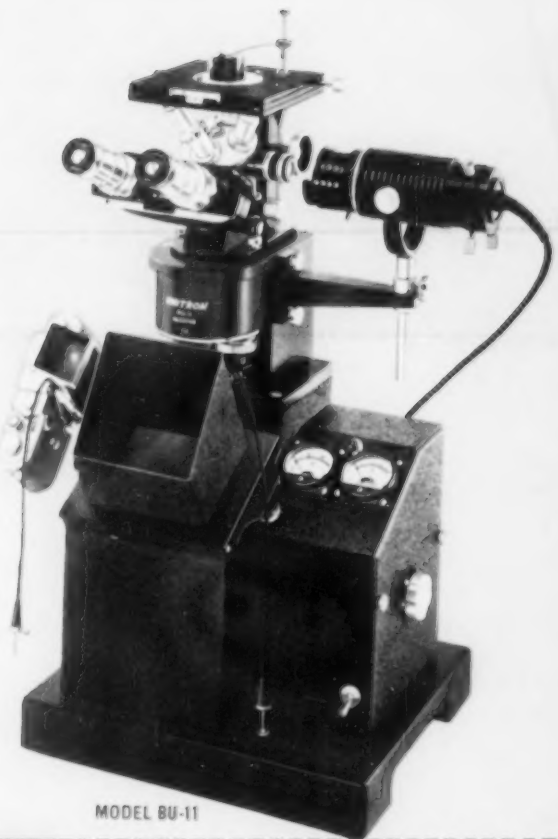
MODEL MEC

UNITRON INVERTED Metallurgical Microscope: This compact unit provides many of the features usually found only in larger metallographs. Standard equipment includes optics for 25–1500X, polarizers, filters, transformer in base, etc. A built-in camera attachment for 35mm. photography is included with the binocular and available for the monocular model. Extra accessories include Polaroid camera attachment, vacuum heating stage and illuminator for transmitted light. Think of the time which your laboratory can save by providing each metallurgist with one of these handy, inexpensive units for use at his desk.

Monocular Model MEC $399 Binocular Model BMEC $615

UNITRON METALLOGRAPH and Universal Camera Microscope: A completely self-contained instrument of modern design for visual observation, photography, projection, and measurement of both opaque and transparent specimens; using bright field, dark field, or polarized illumination. Standard equipment includes all optics for 25–2000X, polarizers, filters, 3¼" x 4¼" camera, and many accessories. Also available are camera attachments for Polaroid, 35mm., and motion picture photography; vacuum heating stage for temperatures to 1500° C.; and macro-objectives (5–40X). Even laboratories on a limited budget can enjoy the precision, speed and efficiency possible only with a complete installation of this type.

Monocular Model U-11 $1195 Binocular Model BU-11 $1379



MODEL BU-11

There is a free 10 day trial offer on any UNITRON Microscope.

Let the instrument prove it's value to you — in your own laboratory — before you decide to purchase.

See for yourself why . . .

THE TREND IS TO UNITRON

SEND FOR YOUR FREE CATALOG. IT'S YOURS FOR THE ASKING ▶

UNITRON INSTRUMENT DIVISION OF UNITED SCIENTIFIC CO.

204-206 MILK STREET, BOSTON 9, MASSACHUSETTS

Please rush UNITRON'S Microscope Catalog 10-E

NAME

ADDRESS

CITY

STATE